# Global Climate Policy Beyond Nation-State Actors

An Economic Analysis of Environmental Cooperation

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# Zusammenfassung

Internationale Kooperation zur Vermeidung von gefährlichem anthropogenen Klimawandel erweist sich als sehr komplex. Viele Schwierigkeiten, ein verbindliches internationales Abkommen mit ausreichenden Reduktionszielen zu erreichen, sind augenscheinlich und werden in bestehender ökonomischer Literatur ausführlich diskutiert. Es entstehen allerdings stetig neue Ansätze und Ideen um Klimakooperation zu fördern. Diese Arbeit untersucht neue Wege der internationalen Klimakooperation und erweitert den Horizont der spieltheoretischen Forschung zu internationalen Umweltabkommen um Ansätze aus der Global Governance, politischen Ökonomie und Außenhandelspolitik. Zudem wird die Übertragbarkeit spieltheoretischer Erkenntnisse aus der Forschung zum Klimaschutz für die transnationale Klimaanpassung diskutiert.

Die Arbeit fundiert in großen Teilen auf analytisch-spieltheoretischer Modellierung. In der zu Grunde liegenden Spielstruktur entscheiden Länder anfangs, ob sie einer internationalen Koalition beitreten oder nicht. Anschließend wählen die Koalitionsmitglieder ihr Emissionsniveau in einem Spiel zwischen der Koalition und den Nichmitgliedern.

In diesem Analyserahmen wird die Option mehrerer gleichzeitig parallel existierender Klimaklubs auf ihr Potenzial zur Verbesserung der Zusammenarbeit und Emissionsminderung untersucht. Darüber hinaus wird der Einfluss von politischen Interessengruppen (Lobbys), die die Interessen von Industrie und Umweltverbänden vertreten, auf die Stabilität internationaler Umweltabkommen analysiert. Dies geschieht durch eine politökonomische Ergänzung des Grundmodells. Die Eignung von Handelssanktionen als Mittel zur Förderung der internationalen Kooperation für den Klimaschutz wird ebenfalls in einem analytischen Modell untersucht und die Auswirkungen dieser Maßnahmen anschließend in einem angewandten allgemeinen Gleichgewichtsmodell quantifiziert.

Die Erkenntnisse der Arbeit zeigen, dass eine Vielzahl von Akteuren und Koalitionsstrukturen eine wichtige Rolle in der Klimakooperation spielen und die Wirksamkeit von Klimapolitik verbessern können. Es zeigt sich, dass das Potenzial multipler Koalitionen entscheidend von den Charakteristika der Nutzen- und Schadensfunktionen der Länder für Treibhausgasemissionen abhängt. Wenngleich die Existenz mehrerer paralleler Koalitionen die Kooperation nicht immer verbessert, ist sie dem Klimaschutz nicht abträglich. Klimaklubs sollten daher als ein möglicherweise vielversprechender Weg für internationale Klimapolitik betrachtet werden.

Weiterhin zeigt die Arbeit, dass sich Lobbyeinflüsse sowohl auf Emissionsreduktionen als auch auf die Koalitionsstabilität von Klimaabkommen auswirken. Lobbyaktivitäten, sowohl von Industrie als auch Umweltverbänden, können unter bestimmten Bedingungen die internationalen Ambitionen zum Beitritt zu einem Klimaabkommen fördern. Der Einfluss von Lob-

byismus sollte somit weder bei der theoretischen Analyse, noch bei der Politikgestaltung zu Klimakooperation vernachlässigt werden.

Während frühere Forschungsarbeiten zum Einfluss von Handelssanktionen auf Klimakoalitionen die Möglichkeit von Vergeltungsmaßnahmen betroffener Länder außerhalb der Klimakoalition vernachlässigen, wird diese in der vorliegenden Arbeit berücksichtigt. Die Ergebnisse zeigen, dass diese Option in strategischen überlegungen von entscheidender Bedeutung sein kann. Wenn Nichtmitglieder Vergeltungsmaßnahmen beschließen können, ergibt sich ein Schwelleneffekt: Ab einer bestimmten Koalitionsgröße ergibt sich eine stabilisierende Wirkung von Handelssanktionen, die größere Koalitionen ermöglicht. In Koalitionen unterhalb dieser Koalitionsgröße überwiegt hingegen der destabilisierende Effekt von Vergeltungsmaßnahmen. Handelssanktionen als wirksame Maßnahme zur Stabilisierung der Klimakoalitionen sind daher wenig attraktiv, wenn Vergeltungsmaßnahmen berücksichtigt werden. Nur wenn sich bereits große Koalitionen gebildet haben, die mehr als die Hälfte des weltweiten Bruttoinlandsproduktes ausmachen, können sie zur Bildung einer globalen Klimakoalition beitragen. Dies ist eine wichtige Erkenntnis für die internationale Klimapolitik, die sich derzeit im Kontext eines zunehmenden Risikos von Handelskonflikten abspielt. Wenn eine Klimakoalition von zu geringer Größe versucht, Außenseiterstaaten zum Beitritt zu zwingen und diese mit Vergeltungsmaßnahmen reagieren, kann dies bereits bestehende Koalitionen destabilisieren.

Eine Einordnung wichtiger Ergebnisse aus der spieltheoretischen Forschung zu internationalen Klimaschutzabkommen in den Kontext der transnationalen Klimaanpassung zeigt schließlich, dass diese dazu beitragen können, Lösungen für Probleme über den Klimaschutz hinaus zu finden.

In einem sich verändernden globalen Klimaregime ist die Suche nach neuen Wegen der Kooperation für eine effektive Klimapolitik von entscheidender Bedeutung. Die Erkenntnisse dieser Arbeit zeigen, dass es sinnvoll ist, den Spielraum der bestehenden spieltheoretischen Forschung zu erweitern. Dies kann dazu beitragen, tragfähige Optionen für verbesserte Kooperation zu finden. Für die Klimapolitik sind neue strategische überlegungen jenseits nationalstaatlicher Akteure von zunehmender Wichtigkeit und die konomische Forschung sollte darauf vorbereitet sein, strategische Empfehlungen zu entsprechenden Politiken zu erarbeiten.

# Summary

International cooperation to avoid dangerous anthropogenic climate change has proven to be very hard to achieve. The difficulties to reach a binding international agreement with sufficient reduction targets are evident and extensively discussed in the economic literature. Nevertheless, new ideas towards cooperation are evolving. This thesis offers an exploration of new avenues to international climate cooperation, widening the scope of game theoretic research on international environmental agreements towards global governance literature, political economy and trade. It also extends the potential applicability of the findings from the game theoretic literature on international environmental agreements for climate change mitigation as it discusses potential insights for cases of transnational climate adaptation.

The analysis is based on analytical theoretical modelling, using a game theoretical model in which countries first choose between joining and not joining an international coalition. Then the coalition members choose their level of emissions cooperatively in a game between the coalition and the outsiders.

It includes the possibility of multiple parallel climate clubs, focusing on their potential to enhance cooperation and emissions abatement. Further, the influence of political pressure groups (lobbies) that represent the interests of the industry and environmentalists on the stability of international environmental agreements is examined. This is done by augmenting the basic model of international environmental agreements with a politico-economic model of political contributions. The potential of trade sanctions to induce international cooperation for climate protection is assessed in an analytical model and the effects of these trade measures are then quantified in a static multi-region, multi-sector computable general equilibrium model of global trade and energy.

The insights of this thesis indicate that a variety of actors and coalitional structures can play an important role for climate cooperation and improve the effectiveness of climate policies. It is shown that the potential of multiple coalitions crucially depends on the characteristics of the countries' benefit- and damage functions of greenhouse gas emissions. Although admit-ting multiple coalitions does not always improve cooperation, they are not detrimental. Climate clubs should, therefore, be considered as a potentially promising avenue for international climate policies.

Lobby contributions turn out to have an important effect on both emissions reductions and coalition stability, with the latter being often not straightforward, depending on the composition of asymmetric countries in an international environmental agreement. Lobby activities from both industry and environmentalists can facilitate international cooperation to abate emissions. This implies that lobbyism should not be neglected in considerations about climate cooperation, neither in policy-making nor in the theoretical analysis.

In contrast to previous work on the influence of trade sanctions on climate coalitions, this thesis considers the possibility of retaliation by targeted countries outside the coalition. The results indicate that this option is crucial in strategic considerations. If outsiders can retaliate, a threshold effect of trade sanctions emerges: Above a certain coalition size, a stabilizing effect from trade sanctions enables larger coalitions whereas in coalitions below that coalition size the effect of retaliatory trade measures predominates and destabilizes the coalition. Trade sanctions as an effective stick to stabilize climate coalitions are therefore less attractive if the possibility of retaliation is taken into account. Only if substantial coalitions of countries that cover more than half of the global GDP have already formed they may help to establish the grand coalition. This is an important finding for international policy-making that currently has to deal with an increasing risk of trade wars with the involvement of the US as an outsider of the climate coalition. If a climate coalition of insufficient size tries to force outsider countries to join and these react with retaliatory measures, this can destabilize existing coalitions or even destroy cooperation.

Finally, with a contextualisation and discussion of the results this thesis shows that insights from the game theoretic literature on international environmental agreements for climate change mitigation can help to find solutions to problems beyond the realm of climate mitigation, such as the example of transnational adaptation.

In a changing global climate regime, the search for new avenues of cooperation is crucial for effective climate policies. The results imply that it is worthwhile to broaden the scope of the game theoretic analysis as this may indeed help to find viable options to increase cooperation. Climate policies increasingly consider new strategies beyond nation-state actors and economics should be prepared to provide strategical advice.

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# 1 | Introduction

Tackling climate change poses one of the most difficult challenges for society worldwide. Anthropogenic greenhouse gas (GHG) emissions have increased with economic and population growth such that the current atmospheric concentrations of carbon dioxide, methane and nitrous oxide are at a level that is unprecedented in the last 800,000 years (Pachauri et al., 2014). To keep "[...] the increase in the global average temperature to well below 2°C above pre-industrial levels [...]" (UNFCCC, 2015) will require significant efforts (Pachauri et al., 2014). Although for many years political efforts have been made to reach a global treaty that leads to effective commitments by nation states, global GHG emission reductions are still far from sufficient to achieve this goal (Climate Analytics et al., 2018; Janssens-Maenhout et al., 2017). From an economic perspective, this can be explained by the fact that climate change mitigation efforts are contributions to a public good which implies that strong free-rider incentives exist. For over two decades, a game theoretic strand of economic literature evolved, that analyzes the formation of international environmental agreements (IEAs) as a means to facilitate contribution to a global public good. This literature mostly focuses on welfare maximizing nation states, depicting individual countries as monolithic players in a game theoretic setting that analyzes the formation of a single IEA for the abatement of GHG emissions (Finus, 2001; Marrouch and Ray Chaudhuri, 2016). In parallel, the governance literature has reported on more diverse approaches towards transnational environmental governance and cooperation (e.g. Biermann et al., 2009; Bulkeley and Castán Broto, 2013) but has not analyzed the strategic inter-dependencies that occur in such arrangements from a game theoretic economic angle.

This thesis explores new approaches towards climate cooperation from an economic perspective. This chapter will set the stage by providing information on anthropogenic climate change and its economic effects, introducing the public good characteristics of climate change mitigation and the resulting need for cooperation. It gives a short overview of climate agreements and the economic literature on IEAs and presents the specific research objectives and methodology of the following chapters of the thesis. In Chapter 2, the scope and limits of the economic literature on IEAs are discussed further and an overview of transnational approaches in the global governance literature is presented. In addition, Chapter 2 introduces two proposals for economic models to analyze climate clubs and city alliances and puts them into context.

Chapter 3 then takes up on the idea of multiple parallel climate clubs and analyzes their potential for cooperation and emissions abatement in a game theoretic model. In the following Chapter 4 the influence of political pressure groups (lobbies) that represent the interests of the industry and environmentalists on the stability of IEAs is examined. Chapter 5 widens the scope of the analysis and includes the trade regime by assessing the potential of trade sanctions to induce international cooperation for climate protection. The insights of the previous chapters that are focused on the mitigation of greenhouse gas emissions are evaluated with regard to their potential for transnational adaptation actions in Chapter 6. Finally, Chapter 7 summarizes the results and implications of all chapters and concludes with a discussion of limitations of the presented research and an outlook on promising ways of further research.

## 1.1 Anthropogenic Climate Change and its Economic Effects

Since the industrial revolution the global economy has grown and increased its GHG emissions rapidly to a current level unprecedented in history. As a consequence, the concentration of the GHGs carbon dioxide, methane and nitrous oxide in the atmosphere have reached a level that is the highest in at least the last 800,000 years (Pachauri et al., 2014). By altering the earth's energy budget through increasing energy uptake of the climate system, cumulative GHG emissions contribute to rises in the average atmospheric temperature. The Intergovernmental Panel on Climate Change (IPCC) assessment finds that since the 1950s the atmosphere as well as the oceans have successively become warmer, global amounts of snow and ice in glaciers and ice sheets have decreased and the sea level has risen. But also temperature and precipitation extreme events have increased. These trends will continue in the future with increasing GHG emissions resulting in rising surface temperature, more frequent and longer lasting heat waves as well as more intense and frequent precipitation events in many regions of the world (Pachauri et al., 2014). These changes in the global climate will have severe impacts on people worldwide as they threaten basic elements of life. The widespread effects include increasing flood risks, reduced dry-season water supply, declining crop yields, ocean acidification that will affect marine ecosystems and fish stocks, rising sea levels, malnutrition and heat stress and increased vulnerability of ecosystems (Stern, 2007). These consequences of climate change are very diverse and unevenly distributed, with low income countries that contribute least to global GHG emissions being most vulnerable (Tol, 2009). To limit these risks from climate change, substantial reductions in GHG emissions to limit climate change are required as well as adaptation measures (Pachauri et al., 2014). Assessing the costs and benefits of climate change mitigation Stern (2007) finds that although the stabilization of the climate causes significant costs, delaying it would be considerably more costly and dangerous.

## 1.2 Why We Need Climate Cooperation

Although scientific evidence indicates clearly that there is a need for the abatement of GHG emissions (see previous Section) we see that global efforts to limit climate change are fare from being sufficient. The fact, that it is impossible to exclude anyone from the benefits of climate change mitigation and that the "consumption" of reduced climate damages does not preclude others from enjoying these benefits makes the abatement of GHGs a global public good. Economic theory clearly predicts that in such a case of a desirable public good, private provision leads to an insufficient level of supply (Mas-Colell et al., 1995). In terms of climate change this means that if countries act unilaterally, global emissions reductions will be far below the social optimum. Following Samuelson (1954), this optimal supply of a public good is characterized by the condition that the sum of the marginal benefits from the public good equals the marginal cost of its provision. As a consequence, the supply of public goods in a given economy is usually seen as a task of the government (Perman et al., 2003). However, regarding climate change, there is in fact no global government that could enforce sufficient contributions of GHG abatement from the countries. Without cooperation and coordination between countries' governments, it will be impossible to mitigate severe anthropogenic climate change.

## 1.3 Climate Agreements and the Economic Literature on IEAs

Since the United Nations Conference on the Human Environment (Stockholm Conference) in 1972 a large number of IEAs has been signed. The Toronto Conference in 1988, where the first CO2 emission targets were set marked one of the first important milestones shortly before the IPCC was established in the same year (Perman et al., 2003). In 1992 the United Nations Framework Convention on Climate Change (UNFCCC) was opened for signature and entered into force in 1994. Its ultimate goal is the "[...] stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system"(UNFCCC, 1992). In the Kyoto Protocol to the United Nations Framework Convention on Climate Change that was signed in 1997 and entered into force in 2005 concrete GHG emission targets and a timetable for their attainment were set (UNFCCC, 1998). However, some of the biggest GHG emitters like China and India were not required to commit to the abatement targets which was a crucial weakness of the protocol and other countries, like the US, did not ratify (Marrouch and Ray Chaudhuri, 2016). Most recently, the Paris Agreement 2015 sets the goal of keeping the global temperature rise below 2°C or even 1,5°C but does not force countries to specific targets and dates (UNFCCC, 2015). So far, the country

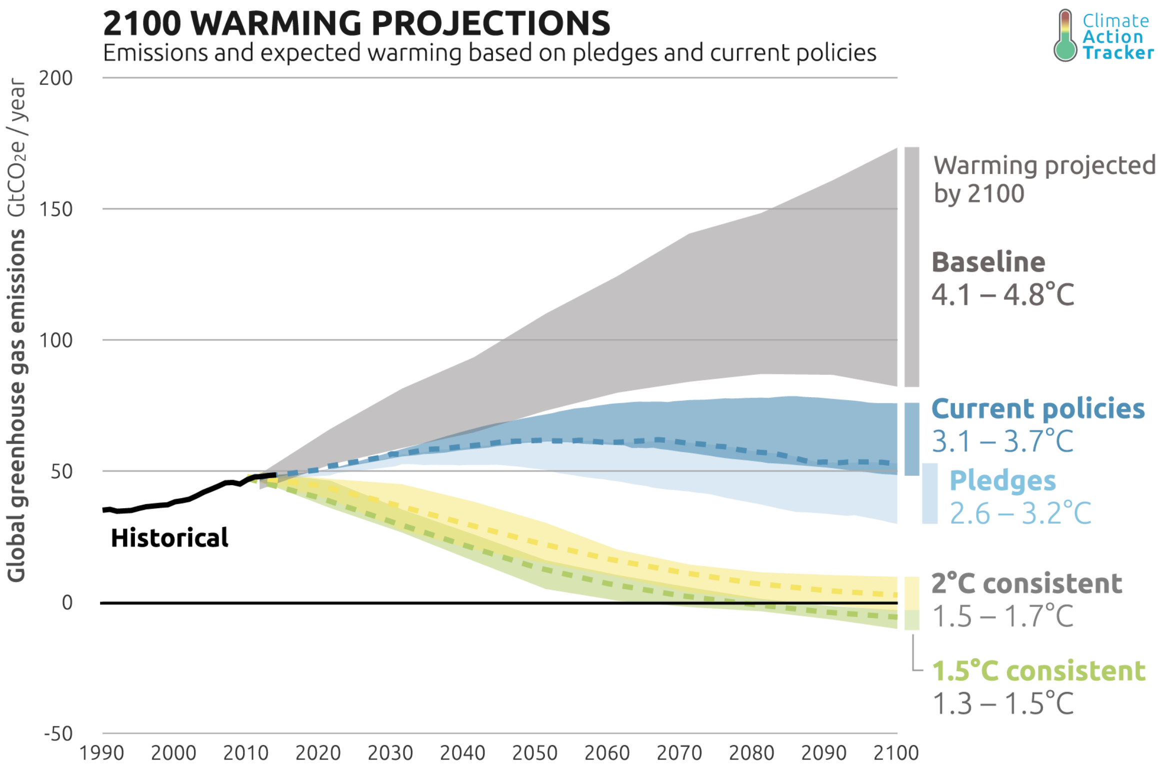


**Figure 1.1:** Emissions and expected warming based on pledges and current policies, source: Climate Analytics et al. (2018).

pledges of GHG emissions abatement fall short of achieving this goal (Climate Analytics et al., 2018) and the agreement does not include a binding enforcement mechanism (Marrouch and Ray Chaudhuri, 2016; UNFCCC, 2015).

Figure 1.1 shows that current policies exceed the pledged emission abatement targets and would lead to a projected temperature increase of 3,1-3,7°C (as of November 2017) and the US Trump administration decided to withdraw from the agreement. So far, the outcomes of the international climate negotiations are in line with the rather pessimistic economic predictions about insufficient contributions to a global public good and do not really manage to tackle the problem.

The urgency of the problem and the difficulty to find solutions has sparked an immense research interest in the formation of IEAs in economics and governance research as well as in other disciplines. Beginning in the early 1990s with seminal papers by Hoel (1992a); Carraro and Siniscalco (1993); Barrett (1994) the game theoretic economic strand of literature focuses on the formation and stability of self-enforcing IEAs. As an important result already early contributions found that self-enforcing IEAs for the contribution to a public good will be either broad but shallow or deep but small or, in other words, they do not bring substantial improvements over the non-cooperative outcome (Barrett, 1994; Finus and McGinty, 2015). In light of these findings the observable lack of effective international cooperation for climate change mitigation on the international arena is not surprising. Since then, the literature has taken into account several approaches that might be promising to overcome these problems. Amongst others, side-payments, issue-linkage, alternative coalition structures and different membership rules have been put into focus (Marrouch and Ray Chaudhuri, 2016). The role of the trade regime and the political economy have recently gained increasing attention as important levers for international cooperation (Wangler et al., 2013; Lessmann et al., 2009; Nordhaus, 2015). But the game theoretical literature is not the only field of research that deals with the challenge of climate cooperation. In analyzing climate change as a collective action problem (Cole, 2008) the Nobel laureate Elinor Ostrom supports the idea of complementing global efforts with small- to medium scale climate governance. The fact that costs and (co-)benefits of climate action occur at multiple scales motivates her call for a polycentric system of climate governance that includes a multiplicity of public and private actors (Ostrom, 2009, 2012). Such a system comprises efforts like city alliances (Cities Climate Leadership Group, 2018), multiple sub-global climate coalitions called climate clubs (Widerberg and Stenson, 2013; Falkner, 2015). However, these important advances to tackle climate change are only sparsely analyzed in game theoretic literature so far. This thesis addresses this research gap.

## 1.4 Research Objectives and Methodology

The main research objective of this thesis is to offer an exploration of new avenues to international climate cooperation, widening the scope of game theoretic research on IEAs towards global governance literature, political economy and trade. Further, it also extends the potential applicability of the findings from the game theoretic IEA literature as it discusses potential insights for cases of transnational climate adaptation. The following main five Chapters 2-6 approach this aim from different angles before Chapter 7 summarizes the main findings and presents conclusions. The following subsections provide a short overview of the main Chapters 2-6 including research objectives and applied methods of the chapters.

### 1.4.1 Transnational Environmental Agreements with Heterogeneous Actors

This chapter serves as a more extensive introduction to the research area of the thesis. It focuses on climate cooperation between different heterogeneous actors, in the course of the chapter called transnational environmental agreements, as complements to the UNFCCC process. The scope and limits of the current economic literature on IEAs are discussed more extensively than in the previous general introduction to the thesis. An overview of relevant publications in the global governance literature and empirical observations transnational environmental agreements helps to transfer new insights and ideas to the game theoretic analysis. These include the consideration of (i) actors that are not nation state governments, and (ii) multiple environmental agreements. Two proposals for game theoretic models that analyze climate clubs and city alliances are made. These illustrative simple models extend standard game theoretic models of IEAs (e.g. Carraro and Siniscalco, 1993; Barrett, 1994). The results show that transnational environmental agreements can be individually rational and can improve effectiveness of climate policies. This chapter is joint work with Leonhard Kähler and Klaus Eisenack and published as Hagen et al. (2017).

### 1.4.2 Climate Clubs vs. Single Coalitions: The Ambition of IEAs

Following and expanding the proposed model structure of the previous Chapter 2, the idea of climate clubs as multiple parallel environmental agreements is investigated in more depth in this chapter. It examines whether global cooperation on emissions abatement can be improved if asymmetric countries are allowed to sign one out of several parallel environmental agreements. Additionally the assumption that countries are symmetric, which is often made in the IEA literature, is relaxed. The analysis is based on a two-stage game theoretical model that allows for multiple coalitions with multiple types of countries. The chapter considers two different possible cases for both the benefits and the damages from emissions: constant and decreasing marginal benefits from emissions and constant and increasing marginal damages from emissions. For all four possible combinations of these benefit and damage functions the potential of multiple agreements to increase global emissions abatement above the outcome with one IEA is assessed and conditions for stable coalitions and the resulting global emissions are determined. The results indicate that the potential of multiple coalitions crucially depend on the characteristics of benefit- and damage functions. In the case of decreasing marginal benefits and constant marginal damages, admitting multiple coalitions increases the number of cooperating countries and reduces emissions compared to the standard case with a single coalition. In contrast, with increasing marginal damages and constant marginal benefits, global emissions are independent of the number of coalitions admitted. If both damages and benefits are non-linear, admitting multiple coalitions can decrease global emissions. The chapter thus contributes to the emerging discussion on the scope and limits of climate clubs. This chapter is joint work with Klaus Eisenack and based on Hagen and Eisenack (2015).

### 1.4.3 The Influence of Political Pressure Groups on the Stability of IEAs

Another important new avenue in the theoretical analysis of IEAs focuses on the political economy and its effects on coalition formation (Wangler et al., 2013). Chapter 4 contributes to this as it examines the effects of political pressure groups (lobbies) on emissions of individual countries and on the stability of IEAs to reduce emissions. In contrast to most of the existing literature on IEAs the chapter does not assume that governments are independent welfare maximizing actors but accounts for the influence of lobby groups on the decision of the governments. In the chapter, two types of lobbies are considered, industry and environmentalists, and asymmetric countries differ in lobby strengths. In the model, lobby-groups in countries that do not join the IEA only have an impact on the emissions abatement of the lobby's host country. By contrast lobby activities in signatory countries have spillover effects on the abatement decisions of other member countries. As lobby strength impacts abatement, it will, in turn, impact the incentives to participate in the agreement. The results of this chapter show that lobby activities from both lobby groups, industry and environmentalists, can facilitate international cooperation to abate transboundary pollution. This, however, depends on the distribution of lobby activities across countries. This chapter is joint work with Juan-Carlos Altamirano-Cabrera and Hans-Peter Weikard and based on Hagen et al. (2016).

### 1.4.4 Boon or Bane? Trade Sanctions and the Stability of IEAs

This chapter provides insights into the potential of fostering international climate cooperation by linking IEAs with the trade regime. The search for new means to support cooperation is of even higher importance than before since the decision of the US Trump administration to withdraw from the Paris agreement has further hampered the efforts to find cooperative solutions on the international level. Trade sanctions in the form of import tariffs are one principal measure discussed as such a means to push cooperation. Former studies have concluded that import tariffs are an effective mechanism to establish international cooperation (Lessmann et al., 2009; Nordhaus, 2015). However, most of these studies rely on the assumption that countries that do not join the IEA are not able to retaliate, i.e. to implement import tariffs themselves. In this chapter, a combination of analytical and numerical analysis is used to investigate implications of retaliation. While trade sanctions that members of an IEA put into place against outsiders stabilize the IEA, retaliatory trade measures from outsiders that target IEA members have a destabilizing effect so that the introduction of trade sanctions together with retaliatory measures has ambiguous effects. The results indicate that a threshold effect exists: below a certain coalition size the effect of retaliation predominates and decreases incentives to be a coalition member. In coalitions above the threshold size the effect of trade sanctions that stabilizes coalitions dominates and enables the formation of larger stable coalitions. The analysis suggests that only after a sufficiently large climate coalition has already been formed, the threat of trade sanctions might be an effective stick to establish the grand coalition. This chapter is joint work with Jan Schneider and based on Hagen and Schneider (2017).

### 1.4.5 What the Economics of Climate Change Mitigation May Tell on Transnational Adaptation

The previous chapters yield insights about new approaches towards cooperation for climate change mitigation. Chapter 6 takes a broader perspective and revisits important insights from the mitigation focused IEA literature to assess their implications for climate adaptation. It contributes to the research agenda on transnational climate adaptation by addressing the cross-boundary spillovers of local adaptation measures. If adaptation in one country affects other countries, adaptation can resemble the problem structure at the core of the economic analysis of climate change mitigation. Like climate change mitigation, adaptation measures can supply public goods across national boundaries. In such cases these measures are likely to be under-provided, which can be amended with appropriate governance arrangements. The IEA-literature has provided insights into such arrangements. From the perspective of adaptation research the question is therefore whether there are lessons to be learned by applying a mitigation perspective to the governance of adaptation with cross-boundary spillovers. This chapter illustrates this approach with reference to the Baltic Sea's eutrophication problem in the context of climate change, highlighting the similarity of the problem structure, and subsequently translating mitigation findings to the specifics of the Baltic context. Focusing on coalition structures, side-payments, issue linkage, and trade sanctions, the chapter critically reviews available governance arrangements, providing new perspectives on the issue of transnational climate adaptation. This chapter is joint work with Matteo Roggero and Leonhard Kähler and currently under review as Roggero et al. (2018).

### 1.4.6 Methodology

The thesis is based on analytical game theoretical modeling. While Chapter 6 and the first part of Chapter 2 are mainly focused on revisiting established results from the game theoretic IEA literature and related streams of research to identify important and promising avenues for future climate cooperation, own models are developed in Chapters 2-5. The basic model structure of these models follows seminal models of the literature (e.g. Carraro and Siniscalco, 1993; Barrett, 1994) and consists of two important game stages. In the first stage of the game all countries decide if they join a coalition/IEA or not. After that, IEA-members decide cooperatively about their emissions but engage in a non-cooperative game with all countries that do not belong to their coalition. The game is solved by backward induction. The stability analysis for the coalitions is conducted by applying the concepts of internal and external stability that were initially borrowed from cartel theory (d'Aspremont et al., 1983). Internal stability implies that no member country has an incentive to leave its coalition. External stability is given if no outsider has an incentive to join an existing coalition. A stable coalition is therefore characterized by internal and external stability i.e. no member country can be better off by leaving the coalition and no outsider country can be better off if it joins the coalition.

This basic model is augmented to account for alternative coalition structures (Chapters 2 and 3) and sub-national actors other than country governments (Chapters 2 and 4). For the politico-economic analysis in Chapter 4 this is done by applying the political contributions approach of Grossman and Helpman (1994, 1995, 1996) which is a standard model to study the influence of interest groups on policy-making. Used by Grossman and Helpman to study the effect of lobby contributions on trade policies, this approach considers self-interested policy-makers who seek to maximize the sum of lobby contributions and the welfare of the median voter in order to increase their chances to be reelected. It has also been applied to study environmental policy-making (e.g. Fredriksson, 1997; Aidt, 1998; Conconi, 2003; Fredriksson et al., 2005; Aidt and Hwang, 2014; Batina and Galinato, 2014).

Additionally, in Chapter 5 the game theoretical model is complemented by a standard static multi-region, multi-sector computable general equilibrium (CGE) model of global trade and energy that was developed for numerical analyses on border carbon adjustments in sub-global climate policies. For a detailed description of the model including an algebraic formulation see Böhringer et al. (2015). This framework is particularly well suited for the analysis of the quantitative implications of trade measures on coalition stability, as global and regional welfare implications of emission abatement and trade policies are fully endogenized. Following Armington's differentiated goods approach, goods in international trade are distinguished by origin in the model (Armington, 1969). The latest version of the database from the Global Trade Analysis Project (GTAP version 9) with base-year 2011 (Aguiar et al., 2016) was used for calibration. This database provides input-output tables, international sectoral trade flows, sector- and fuel specific CO2 data, and substitution elasticities for production and trade for 140 regions and 57 sectors.

# 2 | Transnational Environmental Agreements with Heterogeneous Actors

## 2.1 Introduction

There is unequivocal scientific agreement on the dangerous interference of anthropogenic greenhouse gas emissions with the climate.[1] But efforts to find cooperative solutions on an international level have been mostly unsatisfactory so far. The recent UN climate negotiations in Paris have led to some agreement about global targets, but not about the individual nations' contributions to the global public good. This state of affairs motivates the search for complementary approaches for global emissions reductions. Some suggestions are in the air. For example, some authors think about minilateralism (Eckersley, 2012), climate clubs (Widerberg and Stenson, 2013; Falkner, 2015) or a building blocks approach (Stewart et al., 2013a). Lobby groups and NGOs influence climate and energy policy. City alliances grow in parallel to nation state based coalitions. This chapter aims at exploring some of such transnational initiatives or patterns of cooperation. Although there has been some research on those patterns in the global governance literature (related to political science), we aim at making this topic conducive for economic analysis, in particular game theory. How can such patterns of cooperation be explained? Can we expect cooperation to be effective?

In this chapter we call a contract that stipulates rules for contributions to a global environmental good "transnational environmental agreement" (TEA) if it has heterogeneous contracting parties, i.e. of different type. Parties can be national, subnational, international, or of different quality. Such contracts can be explicit or implicit. They might directly aim at emissions reductions, or only indirectly (e.g. by stipulating monitoring procedures). We chose the term "transnational" to generalize from the established "international" environmental agreement (IEA) framing. Transnational agreements are not undertaken within single jurisdictions (which would not be international either), but the main actors involved do not necessarily need to be

[1] This chapter is based on Hagen et al. (2017).

national governments (c.f. Andonova et al., 2009; Hale and Roger, 2014).

TEAs are not an invention from theory. For example, the C40 Cities Climate Leadership Group (Cities Climate Leadership Group, 2018) with more than 80 megacities (from the South and the North) took leadership in signing the Greenhouse Gas Protocol for Cities in 2014. As of December 2015, the number of signatories increased to 428 cities (Greenhouse Gas Protocol, 2015). Weischer et al. (2012) map 17 climate clubs, being non-universal and partially overlapping agreements of nation states that cooperate on climate change. In total, 122 countries are members of at least one of those clubs. Some of these clubs include non nation state partners. A first study roughly estimates that non-state initiatives might reduce greenhouse gas emissions by 3 gigatons in 2020 (UNEP, 2015). Although the empirical fact that many TEAs already exist might seem impressive at the first glance, some skeptical questions warrant attention. It is well-known, after all, that global public goods suffer from free-rider incentives. So what does motivate actors then to be frontrunners and sign a non-universal TEA? And if they do so for some reason, why shouldn't they not just pretend to reduce greenhouse gas emissions? These questions will be further explored in this chapter.

There are only few papers in economic journals that address TEAs, some of which are discussed in more detail below. The theme of city alliances seems to be broadly neglected (but see Sippel and Jenssen, 2009; Millard-Ball, 2012, for some data analysis). Subnational emission reductions are not analyzed, to our knowledge, from the perspective of cooperation between actors from different countries. The exception is the game theoretic literature on environmental agreements that explain non-universal cooperation (more on that below). Studies that admit for multiple climate clubs are sparse (e.g. Chapter 3, Asheim et al., 2006; Finus, 2008). National lobby groups are addressed by Marchiori et al. (2017); Habla and Winkler (2013) and Chapter 4, but not from a transnational perspective (for a literature review on the political economy of the formation of IEAs see Wangler et al. (2013)). This chapter is not intended to fill all these gaps, but contributes by arguing for the relevance of this research field. It provides structure in transferring insights from global governance research, where much more has been published on transnational climate governance than in economics, to game theory. First, we report on the global governance literature and empirical examples of emerging transnational climate agreements. Then we give an overview of the existing economic literature on the scope and limits of IEAs. Building on these two pillars we follow up with two proposals for game theoretic models. They analyze strategic effects of climate clubs and city alliances as examples for TEAs. We then take a look at the larger picture again and contextualize these approaches in an outlook on promising future research.

## 2.2 Current Transnational Approaches in the Global Governance Literature

This section puts together some selected and documented empirical observations of transnational environmental agreements, and summarizes relevant publications from the global governance literature. Climate clubs can be understood as "Club-like arrangements between states that share common climate-related concerns, and sometimes in partnership with non-state actors such as companies and Non-Governmental Organizations [...]" (Widerberg and Stenson, 2013). Climate clubs are also coined as "minilateralism" (Eckersley, 2012). They are currently analyzed in the discourse on fragmented global governance (e.g. Biermann et al., 2009; Keohane and Victor, 2011; Isailovic et al., 2013). This literature acknowledges that there is no monolithic and rational global governance architecture, but a carpet of loosely-coupled international institutional arrangements and regimes, not all being universal but many overlapping. Although they may address multiple issues, their scope can be synergistic, cooperative or conflictive. One set of overarching questions address the conditions under which fragmentation is conducive or detrimental to regime effectiveness (e.g. Gehring and Oberthür, 2008; Biermann et al., 2009).

Weischer et al. (2012) analyze existing climate clubs and explore their contribution to climate action as well as the incentives for becoming club members and taking action. Similarly, Widerberg and Stenson (2013) find different types of clubs, from political and technical dialogue forums to country strategy and project implementation groups. Examples are the Asia-Pacific Partnership on Clean Development (2006-2011, including the US and China) and the International Energy and Climate Initiative – Energy + (since 2010, International Energy and Climate Initiative – Energy+, 2015). The latter, led by Norway, has 16 national government members (from Africa, Asia and Europe), and multiple non-governmental partners, e.g. the World Bank and the World Business Council for Sustainable Development (WBCSD). It aims at promoting energy efficiency and renewables by incentivizing commercial investments. While some papers focus on the legitimacy of climate clubs (e.g. Karlsson-Vinkhuyzen and McGee, 2013), others focus on their effectiveness (see Moncel and van Asselt, 2012, for an overview).

Different arguments are put forward to underpin the potential of climate clubs. It might be easier to reach agreement in smaller clubs of countries that are more willing to push forward climate protection (based on the argument of Olson (1965)). Falkner (2015) distinguishes three dominant rationales of climate clubs. First, club benefits are created for the members. Second, a re-legitimation of the climate regime by giving great powers a privileged position in the negotiations while acknowledging their greater responsibility at the same time. Third, the potential of climate clubs to enhance the bargaining efficiency of the international negotiations by facilitating agreement amongst smaller groups of players. Further pros and cons of climate clubs will be discussed below. Another case for TEAs are contracts between cities from different countries. City networks on sustainability issue have some tradition. The International Council for Local Environmental Initiatives (since 1990) has more than 1,000 cities, towns and metropolises from all continents as members (ICLEI, 2015). Over 1,700 cities and municipalities are members of the Climate Alliance (since 1990, Climate Alliance, 2015), and have voluntarily committed to reduce greenhouse gas emissions reductions by 10% every 5 years. The C40 Cities Climate Leadership Group (since 2005) pushed the Compact of Mayors (2015), which is currently signed by cities with more than 5% of the global population. The Compact of Mayors has adopted a common monitoring, reporting and verification standard, the Greenhouse Gas Protocol for Cities (Greenhouse Gas Protocol, 2015). The standard is built on experience with a private sector initiative, the Carbon Disclosure Project (Carbon Disclosure Project, 2015), and has established a joint carbon registry.

As with climate clubs, there is also some research on city alliances. A special issue in Local Environment reviewed the early studies (Betsill and Bulkeley, 2007). Interesting questions are the motivations for joining city alliances, and their environmental effectiveness. The early literature is mostly descriptive in nature and undertakes single or comparative case studies. For example, Betsill and Bulkeley (2004) show for six case studies of municipalities in the UK that membership in Cities for Climate Protection (CCP) is mostly motivated by the availability of additional financial and political resources, and not so much by transfer of technical and best practice knowledge. International recognition of the local engagement and the re-framing of existing measures in terms of climate change helps increase legitimacy and place those activities higher on the local agenda. Gustavsson et al. (2009) explore the potential of city networks for Swedish cities. Kern and Bulkeley (2009) analyze modes of cooperation in three transnational municipal networks (Climate Alliance, CCP and Energie-CitÃľs). Members are active to quite different degrees in terms of information and communication, funding, recognition, benchmarking and certification.

Bulkeley and Castán Broto (2013) collected an impressive database with more than 600 'urban climate change experiments' from 100 systematically selected global cities. All these experiments are explicitly targeted at reducing greenhouse gas emissions or at adapting to climate change. Most experiments are found in Europe, Latin America and Asia. Less of them relate to adaptation, but many to urban infrastructure, the built environment and energy. Half of the experiments involve partnerships, for example between local governments and the private sector. More recently, Hakelberg (2014) collected a sample of 274 European cities of which 41% became members of city networks until 2009. The econometric analysis shows that membership in a city network increases the likelihood of adopting a local climate strategy. In contrast, there is no such effect on geographically neighboring cities. Top-down governmental policies have a stronger effect on local climate strategies than city network membership.

Some studies explore the reasons why city alliance exist and might (not) be effective. Bulkeley (2010) generally stresses the changing role of cities and states in political systems, and highlights political economy reasons. Furthermore, urban areas are expected to be particularly vulnerable to climate change, though some more so than others (e.g. Pachauri et al., 2014; Corfee-Morlot et al., 2009; Gill et al., 2007; Campbell-Lendrum and Corvalán, 2007). This might contribute to urgency in climate change adaptation and mitigation in some cities. Generally the local approach offers potentially easier stakeholder engagement, concrete action, resource mobilization and investment, mostly because actors are directly involved (e.g. Corfee-Morlot et al., 2009; Sippel and Jenssen, 2009). On the other hand, urban action cannot be understood as being disconnected from national law. While the latter sets the context for the former, the former can help enforcing national action by contracts, building trust and through the political process. As a further reason, there might be local co-benefits due to investments, local pollution, or first-mover advantages if a city specializes in technological solutions (although e.g. Urpelainen (2009) shows that local co-benefits are not sufficient to motivate local frontrunners). Further pros and cons of city alliances will be discussed below.

Approaches to study city alliances, climate clubs, and other modes of transnational environmental agreements resonate with different literature streams. Some scholars study subnational climate policies from the multi-level perspective (e.g. Betsill and Bulkeley, 2006; Monni and Raes, 2008). Hooghe and Marks (2003) disentangle different modes that might be helpful to characterize different transnational governance patterns. Type I governance refers to hierarchically nested arrangements (like in a classic federal system), while Type II governance refers to arrangements that cross hierarchies or overlap between jurisdictions. The literature on fiscal federalism (Oates, 1972, 2005) and environmental federalism (Shobe and Burtraw, 2012) uses more economic concepts to study the allocation of policies between subsidiarity and centralization. This approach might be helpful to study TEAs.

The debate on transnational climate governance got further impetus from Elinor Ostrom after her Nobel laureate speech (Ostrom, 2010, 2012). She rooted the considerations on addressing climate change both down from the top and up from the bottom in the concept of polycentric governance. In such governance modes many centers of decision making, which are formally independent from each other, make mutual adjustments for ordering their relationships (Ostrom et al., 1961). This line of inquiry was taken up further by Cole (2011) and recently by Jordan et al. (2015).

## 2.3 Scope and Limits of IEAs

IEAs with a focus on climate agreements have been analyzed in the economic literature since the 1990s. It has led to the development of various models that serve as a starting point for the analysis of TEAs. This section gives an overview of this strand of research and its main assumptions and results.

The literature on IEAs started with the seminal work of Carraro and Siniscalco (1993) and Barrett (1994). The basic idea is to transfer concepts from the theory of economic cartels (d'Aspremont et al., 1983; Chander and Tulkens, 1995) to the study of stable coalitions that contribute to a public good. A large set of publications that refined the first contributions followed suit, with further analytical and simulation studies up to date. Most of this research is based, inter alia, on the following propositions:

1. Global environmental problems are about provision of public goods.
2. Players are aspiring and achieving individually rational decisions in a game theoretic framework.
3. International environmental agreements need to be self-enforcing.
4. Players are nation states, their payoffs are determined by national welfare.
5. Full global cooperation (the grand coalition) would yield the first-best outcome.
6. The social optimum is ideally achieved, in principle, by a single global policy instrument (e.g. a uniform carbon tax or an emission trading scheme).

Based on these propositions, some standard insights have been consolidated over a broad range of settings. Some of them can be stated in a stylized way as follows. [i] The social optimum cannot be achieved due to free rider incentives. [ii] If some countries or coalitions undertake unilateral emission reductions, their effect is dissipated due to carbon leakage. [iii] Cooperation is either broad but shallow, or deep but small. Thus, if we assume that reducing carbon emissions is associated with high mitigation costs and small damage reductions, a stable coalition will not have many signatories.

Although scientifically robust, these results are politically mostly frustrating. They do a good job in explaining the long-lasting stalemate and questionable effectiveness of the climate negotiation process under the UNFCCC.

Taking on that, two questions remain. First, if these results are valid for the climate case, is there any chance to avert the greatest market failure ever (Stern, 2007) or, more pathetically, loss of life and quality of life for billions of people? Is there no alternative to accepting the inevitable? Second, are these results indeed valid for the climate case?

Some skeptical remarks may deserve attention. For example, some studies have determined social costs of carbon of just a few dollars per ton (in particular for higher discount rates, (Pachauri et al., 2014)). Several other studies have shown that the costs of mitigating emissions to limit greenhouse gas concentrations below 430 - 480 ppm by 2100 lead to a reduction of consumption growth by 0.04 to 0.14 percentage points over the 21st century (Pachauri et al., 2014), i.e. these costs might be relatively low. If at least one of these kind of conclusions is valid, it seems that the gains from cooperation are shallow. The theory would thus imply broad cooperation. This implication is falsified by over 20 years of slow progress in climate negotiations.

Furthermore, the empirical examples of TEAs outlined above cannot be explained by the standard insights. Why should multiple climate clubs on overlapping issued be formed? Why do some climate clubs engage, although probably on a low level, in unilateral action? Why do cities from different countries start cooperation on emissions reductions, although most of their national governments do not, although there is no (single) global policy instrument in place, and although there are still many cities that do not participate in city networks? Instead, theory would predict cities to be free riders.

Solving such puzzles seems to be important both for climate protection and for scientific inquiry. One starting point for analysis could be to reconsider some of the six propositions outlined above. In the following, we want to explore how proposition (3), (4) or (5) might be relaxed, while keeping the remaining propositions.

## 2.4 Proposals for Theoretical Analysis

In this section we give two selected proposals for economic models that concentrate on transnational environmental agreements: climate clubs and city alliances. Both can be observed empirically. However both have got little attention in the economic literature so far even though they offer interesting concepts. We give general outlines for these two approaches that can serve as seeds for further model development. In addition, we give a detailed outlook on promising lines of further research in these and related areas.

### 2.4.1 Climate Clubs

One way to open up the classical approach of one single international environmental agreement is to allow heterogeneous countries to form climate clubs. As described in the global governance literature, climate clubs may have different effects and may improve over one monolithic agreement through different rationales (c.f. Falkner, 2015). The aspect of club benefits for the members of a climate coalition is analyzed by Nordhaus (2015). He finds that a climate club that imposes trade sanctions on non-participants can induce a larger stable coalition with more abatement than a coalition without sanctions. Asheim et al. (2006) model the case of symmetric countries and two coexisting agreements. The countries are partitioned in two regions and can choose whether they sign an agreement for that region or not. They conclude that a larger number of cooperating signatories can be sustained, compared to the standard case of a single IEA. The case of two coexisting TEAs is further analyzed in a numerical study by Osmani and Tol (2010) who additionally consider two asymmetric country types in a three-stage sequence of play between the coalitions and the non-signatories. Their results show that the possibility of two coalitions could increase as well as decrease emission abatement in comparison to the standard case with one coalition. Going beyond numerical examples, Chapter 3 studies the effect of multiple coexisting climate clubs in an analytical game theoretic setting. The paper allows for asymmetric countries and investigates if global cooperation for emission abatement can be improved if countries can form coexisting TEAs. This very general analytical approach to climate clubs helps to get insights in the effects of negotiating coexisting climate clubs without being bound by specific assumptions on the concrete costs and benefits of countries emissions abatement. The rationale of this analysis will be introduced for the simplest version of this game theoretic climate clubs model. Its main results are derived and discussed. The model is set up in the widely-used two-stage game structure with countries first choosing to join a coalition or not (e.g. Carraro and Siniscalco, 1993). In the second stage the members of a coalition decide cooperatively on the amount of emissions abatement that is undertaken by the coalition. The game is solved by backward induction. In contrast to the bulk of the existing literature, coexisting agreements are possible. Each stage of the model is set up as a simultaneous Nash-game. The simplest version of the model already allows for important insights to the idea of climate clubs. It considers two types of asymmetric countries and two possible TEAs. The number of abating countries of type $i$ ($i = 1, 2$) is denoted by $z_i$. We assume linear benefits of global emissions abatement and a binary choice for countries between abatement, which is associated with abatement costs $c$, and pollution. An abating country of type $i$ gets the payoff $\pi_i^a = -c + \alpha_i(z_1 + z_2)$. Asymmetric benefits of the countries are expressed by the parameter $\alpha_i$ where $\alpha_2$ is normalized to $\alpha_2 = 1$ and $\alpha_1 \in [0, 1]$. A type 1 country therefore benefits less or at most as much as a type 2 country from abatement. The net benefit of own abatement of each country is negative since $c > 1$. Thus, playing pollute is the dominant strategy if there is no TEA and all countries play pollute in the non-cooperative Nash equilibrium. In the first stage of the game countries decide about their TEA-participation. The case of one agreement is compared to that of two coexisting agreements. Variables referring to the game equilibrium with one agreement are denoted with a $*$ superscript, those referring to the equilibrium with two agreements with a $**$ superscript. In the first case countries of both types can choose to join or not to join the agreement. In the other case each agreement consists of similar countries, representing e.g. regional agreements (c.f. Asheim et al., 2006). Solving the second stage of the game first, the agreements cooperate internally in their decisions about their emissions abatement. In the two agreements case the agreements take their decisions independently and simultaneously. Maximization of the respective joint payoffs yields the second stage equilibrium with agreement i playing

$$z_i^* = k_i \quad \text{(abate) if } \alpha_1 k_1 + k_2 > c, \tag{2.1}$$

$$z_i^* = 0 \quad \text{(pollute) if } \alpha_1 k_1 + k_2 < c. \tag{2.2}$$

with $k_i$ denoting the number of type i signatories. This result already shows that the decision of each agreement depends on the number of its members, but not on the abatement decisions of the other countries. The application of the criteria of internal and external stability solves the first stage of the game. As playing pollute is a dominant strategy for non-signatories, internal stability is only given if the members of an agreement choose to abate and would change from abate to pollute if one country left the agreement so that $c > \alpha_1(k_1^* - 1) + k_2^* > \alpha_1 k_1^* + (k_2^* - 1)$. The stability conditions together with this linchpin condition indicate that a stable abating agreement may consist of countries of both types with the number of signatories satisfying

$$c + \alpha_1 > \alpha_1 k_1^* + k_2^* > c. \tag{2.3}$$

Setting either the number of type 1 or of type 2 members in the agreement to zero we get the results for the size of the single agreement if it consists only of type 1 (2.4) or of type 2 (2.4) countries:

$$c + \alpha_1 > \alpha_1 k_1^* > c, \tag{2.4}$$

$$c + 1 > k_2^* > c. \tag{2.5}$$

As the abatement decisions in the case of two agreements are mutually independent, the total number of abating countries in this case can be found by adding (2.4) and (2.5) and thus has to satisfy

$$2c + \alpha_1 + 1 > \alpha_1 k_1^{**} + k_2^{**} > 2c. \tag{2.6}$$

By comparing the equilibrium abating stable coalitions in the case of one single and two coexisting agreements we find that two agreements lead to a greater number of agreement members as well as to a greater amount of global emissions abatement and welfare. This effect would be replicated for any larger number of admitted climate clubs. It is caused by the coalitions' and the outsiders' dominant abatement strategies which stem from the linear payoff-structure of the model. As shown in Chapter 3 linear benefits of abatement always lead to dominant abatement strategies, while other cost and benefit structures from emissions abatement may lead to non-dominant reaction functions. In the extreme case of linear costs and concave benefits from abatement, only one agreement would undertake emissions abatement while all other countries do not abate any emissions regardless of their potential membership in other agreements. The findings of Eisenack and Kähler (2015), who show that individual countries with convex benefits from abatement may have increasing reaction functions so that emissions abatement becomes a strategic complement, give rise to the question about the strategic behaviour of clubs that consist of such countries. In light of the previous analysis and the already existing economic literature we may conclude that climate clubs improve the outcomes of climate negotiations in some cases. Even in the least desirable cases we find that the outcome of negotiations with climate clubs leads to the same amount of global emissions abatement as would be achieved with one single IEA.

### 2.4.2 City Alliances

Cities are important actors regarding global climate change, both on the emitting and on the damage side. It might generally make sense that they organize an alliance among themselves in order to tackle these problems. In our proposed model we focus on the economic arguments of vulnerability, local co-benefits and enforceability. The problem of enforcing an environmental agreement can be greatly diminished as cities are not "above the law" like nation states in the international system. They can be bound to abide to contracts by national laws. This makes trust, compliance and enforcement less challenging problems. Generally, there are political, social and cultural links between rural and urban areas of one country. Additionally, a city alliance can introduce a voluntary and legal link between urban areas of multiple countries. The combination of these links might yield more cooperation than the usual economic approach of considering only a voluntary and self-enforcing agreement between countries. Cities are potentially more vulnerable to climate change than other regions (Hallegatte and Corfee-Morlot, 2011). Therefore they have stronger incentives to reduce climate change impacts. There can also be local co-benefits in mitigation, e.g. with the removal of air pollution (Harlan and Ruddell, 2011; Bollen et al., 2009) or a specialization on business opportunities from technological solutions like green energy (Jochem and Madlener, 2003). Particularly early movers may have an advantage here. For technical reasons we characterize the actors in this section by their benefits and damages from emissions (in contrast the model specifications in the previous section). In our model each country $i$ consists of one city and one rural region. The payoff of each city $\pi^i_{city}(e^i_{city}, e) = B^i_{city}(e^i_{city}) - D^i_{city}(e)$ and each rural region $\pi^i_{rural}(e^i_{rural}, e) = B^i_{rural}(e^i_{rural}) - D^i_{rural}(e)$ depends on the benefits $B^i_{city}, B^i_{rural}$

from its own emissions $e_i$, and, as usual, on the damage $D^i_{city}, D^i_{rural}$ from global emissions $e = e^i_{city} + e^i_{rural} + e^{-i}$. The local emissions are an essential (but partly substitutable) factor of industrial production, they are linked to local benefits. Global emissions change the climate, which in turn creates local damages. In line with standard IEA literature (e.g. Hoel, 1991) we assume for all regions positive but decreasing marginal benefits from local emissions $B^{i'} > 0, B^{i''} < 0$ and positive and increasing marginal damages from global emissions $D^{i'} > 0, D^{i''} > 0$. We further assume the following properties of the benefit and damage functions:

$$D^{'}_{city}(e) > D^{'}_{rural}(e), \tag{2.7}$$

$$B^{'}_{city}(e^i_{city}) < B^{'}_{rural}(e^i_{rural}), \tag{2.8}$$

$$B^{''}_{city}(e^i_{city}) > B^{''}_{rural}(e^i_{rural}). \tag{2.9}$$

The first property corresponds to the comparatively higher vulnerability of cities. The second and third inequalities result from assuming local co-benefits from emissions reductions in cities (e.g. lower air pollution or a head start in green technology development). These co-benefits compensate for the loss of benefits from emissions reduction and therefore lead to a lower net loss of benefits from local greenhouse gas production. The model comprises two stages: First, each city decides whether it wants to participate in a TEA by entering an alliance with all other willing cities. Second, each country decides on the emission level of its city and rural region. The entry decision ($c^i \in \{A, \neg A\}$) in the first stage is based only on the payoff of the city: Is $\pi^i_{city}$ higher as an alliance member? The payoff of the rural regions or the other cities does not enter consideration here. In the second stage of the game, countries choose the emissions that maximize their respective payoffs $\Pi^i$. If the city region of a country has entered an alliance, we assume that the country considers the damages to foreign cities of the alliance $D^{A\setminus i}_{city}$ to some degree. This works similar as in stable agreements between nation states that fully internalize all damages from the emissions to all other agreement members. The degree of internalization of foreign cities in an alliance where domestic cities are members is represented by a weight $x \in ]0, 1[$ because cities may not be able to force their national governments to fully integrate a city alliance into their emissions planning. The optimization problem of each country i in the second stage is:

$$\max_{e^i_{city}, e^i_{rural}} \Pi^i(e^i_{city}, e^i_{rural}, e^{-i}) =$$
$$\begin{cases} \text{if } c^i = \neg A: & \pi^i_{city}(e^i_{city}, e) + \pi^i_{rural}(e^i_{rural}, e) \\ \text{if } c^i = A: & \pi^i_{city}(e^i_{city}, e) + \pi^i_{rural}(e^i_{rural}, e) - xD^{A\setminus i}_{city}(e). \end{cases} \tag{2.10}$$

We assume that all countries simultaneously play a Nash game at this stage. In the first stage all cities determine simultaneously in a Nash game

$$\max_{c^i \in \{A, \neg A\}} \pi^i_{city}(e^i_{city}, e) = B^i_{city}(e^i_{city}) - D^i_{city}(e). \tag{2.11}$$

It is obvious that an alliance between cities is easier to reach than an agreement between countries. Due to their high vulnerability, cities value emissions reductions more; at the same time they are more likely to accept emission reductions because they have lower marginal benefits from emissions. The largest part of the emissions reductions (in comparison to a status without any agreement) is borne by the cities in the alliance, because their benefits are reduced least if they lower emissions. They also have the largest reduction in damages. The rural areas (of the countries in which the cities are in the alliance) have to make some emission reduction effort as well, but their main contribution is not allowing any leakage. In a negotiation which only allows for nation states to form an agreement, even rural areas might want an agreement, but free-rider incentives are much higher for them than for cities. Therefore they would prefer others to form an agreement and stay singletons themselves. The national government is important in our model insofar as it ensures that no leakage of "dirty" industry from cities to rural areas occurs. Of course the willingness of governments to engage in local climate policy is important as well. However in this model they don’t have to enforce large emission reductions in (unwilling) rural areas, they only have to prevent them from increasing their emissions. Maintaining a status quo is more feasible in many political cases than enforcing unwanted change. We conclude that if cities can form a mitigating alliance which national governments consider to some degree in their policy decision making, more cooperation and larger emission reductions can result. Cities have an incentive to enter a city alliance because they expect higher damages from climate change and have lower costs of emission reduction than other regions (particularly taking into account co-benefits from greenhouse gas mitigation).

## 2.5 Outlook

There are many further approaches tor transnational environmental agreements in addition to the analysis of those proposed above. We think that they offer promising extensions of the state of the art in research on IEAs. We sketch some of them in the following. Concerning climate clubs, one could think of overlapping clubs as an alternative to the proposed setting of coexisting disjoint clubs. If countries would be signatories of more than one climate club, this would change the strategic interaction of the clubs and possibly also the reaction functions in the game. Another way to include climate clubs as disjoint coalitions in the climate negotiations is to allow countries to form sub-coalitions in a first stage, followed by multilateral negotiations between the coalitions and remaining non-signatories. Possible effects of climate clubs in a broader sense include the generation of club-benefits as proposed, e.g., by Nordhaus (2015). By the creation of such benefits that only favor signatories of a climate agreement, the incentives to join are strengthened. This could be implemented through issue-linkage. Existing international agreements on other topics as, e.g. trade, would then be linked to climate agreements. Existing research on IEAs and trade (e.g. Eichner and Pethig, 2015) could serve as a starting point here. Such multi issue clubs as well as climate clubs that do not negotiate on emission reductions but other issues like monitoring or technology sharing are a challenging but interesting modeling task. With regard to transaction costs we can say that, on the one hand, a shift towards smaller clubs of negotiating countries could possibly lower the transaction costs of forming a climate agreement, while possible interactions between clubs could impose additional transaction costs. There are several economic arguments for an alliance between cities for emissions reductions. In our modeling approach we use vulnerability, local co-benefits and enforceability. In addition to these assumptions, we suggest three more possible reasons in favor of city alliances. First, transaction costs are potentially lower. The implementation of policy measures might be easier on a subnational than on a national level. Second, there is presumably less reason to behave opportunistically in moral hazard situations. The problem of individually rational but collectively harmful behavior can be reduced if people directly observe each other. It might even be argued that urban areas are more likely to have a clientele that shares common norms, such as a collective commitment to behave responsibly and to abstain from opportunistic behavior. Within such a group, information asymmetries are less problematic in a moral hazard configuration. Third, there can be learning effects. Transfer of policies between cities or even from a subnational to a national level could be modeled. Our modeling proposal for city alliances can be combined with research on climate clubs. Cities within countries with low ambition could join climate clubs and exert their influence on the respective countries to join such agreements and take climate action. We actually observe that there are multiple city alliances in place, so these are, in our terminology, coexisting climate clubs of cities. What is the rationale and environmental effectiveness of cities forming coexisting TEAs, and how might cities strategically interact with national governments in heterogeneous TEAs where both cities and countries are members? Apart from city-alliances and climate clubs there are many other actors that could participate in TEAs. Non-state-actors play an important role for adaptation to climate change as well as for mitigation of emissions. Industry lobbies and transnational NGOs influence governments and groups of countries in different ways while subnational governments and internal politics also play an important role for the decisions national governments take. Involving these actors in transnational agreements might open up new possibilities for negotiations and climate action but also raise threats to effective agreements. Whether they are within an agreement between nation states or within a coalition only consisting of non-nation state actors, their interests differ substantially so that the effects of heterogeneity on their outcomes are not clear. These effects should not be neglected and deserve more attention in further research.

## 2.6 Conclusions

This chapter provides an exploration of some transnational initiatives for climate cooperation. The global governance literature finds ample empirical evidence for emerging TEAs. These can be only partially explained by the conventional economic literature which emphasizes the role of nation states with free-rider incentives. We thus propose that more research is needed to understand and evaluate the role of TEAs in order to contribute to deal with climate change. We argue that this particularly requires to consider the strategic interaction of heterogeneous actors, not only nation state governments, and to consider coexisting and possibly overlapping contracts that stipulate emission reductions or other institutions that are conducive to this aim. To illustrate and underpin this claim, we extend already existing game theoretic approaches to IEAs in order to analyze the strategic effects of TEAs. Our two examples show that both climate clubs and city alliances may be able to lead to an increase in emissions abatement and in global welfare. Climate clubs offer an opportunity to cooperate in more than one agreement at the same time. Cites can form alliances in which they agree to mitigate greenhouse gases; the effectiveness of such TEAs will depend on the political influence cities have on national governments. We find that cooperation can be individually rational, even in the presence of free-rider incentives. Depending on the characteristics of the actors, negotiation structures can facilitate cooperation. Multiple agreements, for example, can stimulate more countries to cooperate than a single IEA. National political and legal institutions can be used to avoid the problem of non-binding agreements if actors other than nation states cooperate. Cities, rural regions and other subnational actors can be compelled by law to enact an agreement. Both examples of TEAs have shown that such agreements may indeed be effective and improve over the standard single IEA consisting only of nation states. Depending on the structure of costs from mitigation efforts and damages from climate change, the example of climate clubs shows that it is not in any case clear if TEAs take climate action beyond lip service. Beyond these two examples, there are various other settings of heterogeneous actors that might be conducive to tackle climate change. Other forms, mechanisms, and players in transnational environmental agreements, like NGOs, issue linkage, policy learning, moral hazard and political economy warrant further attention. Also cooperative game theory may be used to model TEAs. Although we have shown that game theoretic analysis might well be helpful to better understand the formation and effects of TEAs, it is clear that it also has its limitations. Some aspects like the re-legitimation of the climate regime (c.f. Falkner, 2015) or potentially irrational behavior of agents are difficult to analyze in a game theoretic setting and might be better researched by other means. One can also question the legitimacy of TEAs with non-state actors in contrast to multilateral IEAs negotiated by national governments. Nevertheless, we argue that especially with regard to the slow progress of the international climate negotiations, and in light of the empirical development already going on, it is important to include non-state actors complementary to an IEA. Non-cooperative game theory offers a conservative view on agreements, i.e. it tends to underrate cooperation incentives (Carbone et al., 2009). Therefore our positive findings carry a particularly heavy meaning; we expect a real potential for TEAs. Institutions and negotiation structures for climate governance can improve if they allow for transnational actors. A combination of different scientific approaches sharpens the view. The global governance literature widens the horizon for economic analysis and challenges the conventional theory of IEAs, as it offers observations that cannot easily be explained by existing models. This is both a provocation and great opportunity for further theory building. Economics offer rigorous methods for the analysis of incentives for cooperation, and model results can give new ideas for TEA-structures and negotiation processes. Understanding TEAs is of the highest importance, particularly in the light of the Paris agreement of 2015 which does not provide binding emission reduction targets for nation states. This challenges both the negotiating actors and research. This chapter sketches several promising policy options and avenues for further research.

# 3 | Climate Clubs vs. Single Coalitions: The Ambition of IEAs

## 3.1 Introduction

Most game theoretical studies on IEAs assume that there is (at most) one self-enforcing agreement on emissions abatement (e.g. Barrett, 1994, 2001; McGinty, 2007; Pavlova and de Zeeuw, 2013).[2] Another frequent assumption in the theoretical literature is that countries are symmetric (e.g. Barrett, 1994; Asheim et al., 2006). In light of the slow progress in international climate negotiations up to the Paris agreement, and due to the new types of partnerships being sought, the idea of climate clubs is drawing increasing attention (e.g. Weischer et al., 2012; Ostrom, 2012; Widerberg and Stenson, 2013). Some authors argue that the focus on a single universal agreement has been the main obstacle to global emission reductions under the United Nations Framework Convention on Climate Change (UNFCCC) (e.g. Stewart et al., 2013b; Falkner et al., 2010). Multiple parallel agreements among nation-states might promise greater contributions to the global public good[3].

We study the effects of climate clubs by allowing for multiple coalitions and relaxing the symmetry assumption at the same time. In the broad literature on IEAs (see also Bloch, 1997; Finus, 2001; Benchekroun and Long, 2012, for earlier overviews), there is, to our knowledge, only a small strand of literature investigating multiple IEAs and asymmetric countries. Theoretical studies with asymmetric countries (but at most one agreement) show that in some cases, global cooperation can be improved (Barrett, 2001; Fuentes-Albero and Rubio, 2010; Heugues, 2012; Pavlova and de Zeeuw, 2013; Eisenack and Kähler, 2015). These insights are roughly mirrored in simulation studies (e.g. McGinty, 2007; Biancardi and Villani, 2010; Ruis and de Zeeuw, 2010). There are also theoretical studies with multiple coalitions (but symmetric countries) which show that a larger number of cooperating members may be sustained (Yi, 1997;

[2]This chapter is based on Hagen and Eisenack (2015).

[3]We use the concept of climate clubs, which is used in the literature (e.g. Weischer et al., 2012; Widerberg and Stenson, 2013) to denote a non-universal agreement that comprises some but not all UNFCCC member states. This is different from the notion of climate clubs proposed by Nordhaus (2015), defined as a single agreement that provides club benefits to its members.

Ray and Vohra, 2001; Bloch, 2003; Finus and Rundshagen, 2006; Asheim et al., 2006). Both multiple coalitions and asymmetric countries are investigated by Bauer (1992). She assumes linear benefits from emission reductions and allows for countries that are identical in structure but asymmetric in size. Coalitions of two countries form. If these coalitions are allowed to engage jointly in further coalition building, larger coalitions are possible. Other contributions (e.g. Osmani and Tol (2010), Bosello et al. (2003), Eyckmans and Finus (2006)) use simulations to analyze asymmetric countries with more than one coalition and find that the situation can be improved compared to the standard case with one agreement. In contrast to previous studies, this chapter contributes to the theoretical literature by analyzing multiple climate clubs in the presence of structurally different countries.

Our model features an arbitrary number of country types and coalitions. Each country can choose whether to join one of a number of agreements or not to sign any of them. Each agreement is framed as a (stable or unstable) coalition, and its members act cooperatively. The simultaneous play game between the coalitions and the outsiders is non-cooperative. Our research thus extends the seminal work of Barrett (1994) and Carraro and Siniscalco (1993) as part of the latter strand of the literature in that it analyzes the internal and external stability of coalitions (d'Aspremont et al., 1983) in a setting with simultaneous play. We derive analytical results for a large class of damage and benefit functions (decreasing marginal benefits of emissions or increasing marginal damages of emissions). In this respect, we take a more general approach than previous work, which has often used a specific parametrization of damage and benefit functions. For the case of both benefits and damages being non-linear, we obtain results for a standard quadratic case. By analyzing simultaneous play of multiple coalitions, we avoid arbitrary assumptions about which of the coalitions moves first. In doing so, we confirm but also qualify some of the results from existing studies with different assumptions.

We find that for the expository case with constant marginal benefits and damages, total emissions decrease with the number of possible coalitions. In equilibrium, multiple stable coalitions emerge and have dominant emission strategies. This result still holds if we relax the assumption of linear benefits and allow for arbitrary (and asymmetric) concave benefits of emissions. The results differ drastically in the case of arbitrary (asymmetric) convex damages functions and linear benefits: global emissions are identical to the standard case with only a single coalition. There can only be one stable and abating coalition. Finally, we explore a case with both convex damages and concave benefits. We find that also in this case, global emissions can be reduced by allowing for more than one coalition.

The next section is devoted to the expository case of linear damages and benefits of emissions. The subsequent Section 3.3 analyzes the effect of multiple coalitions for the different cases. A summary and discussion concludes the chapter.

## 3.2 Climate Clubs with Linear Benefits and Damages

For exposition, we start with simplest formulation of benefits and damages from emissions. We consider the case of two country types and compare the standard setting that allows at most one coalition with a new setting where two parallel coalitions are in place. The model assumptions for the case of one coalition follow Barrett (2001, 2003), extended by allowing for two disjoint parallel coalitions.

There are $N$ countries of either type 1 or type 2. Emissions of a country of type $i$ are denoted by $e_i \in [0, 1]$, and total emissions by $E$. A type $i$ country $(i = 1, 2)$ gets the payoff $\Pi_i(e_i, E) = \beta e_i - \delta_i E$, with $\beta > 1$. The parameter $\beta$ might also be understood as marginal abatement costs. The asymmetry of the countries is expressed by the parameter $\delta_i \in [0, 1]$. For convenience and without loss of generality, we normalize $\delta_2 = 1$. A type-2 country therefore suffers at least as much damage as a type-1 country from emissions. Due to the linear payoffs, each country of type $i$ chooses between playing pollute $e_i = 1$ and playing abate $e_i = 0$. Since $\beta > 1$, the net benefit of playing pollute, $\beta - \delta_i$, is positive for every country. Thus, playing pollute is the dominant strategy if there is no coalition: in the non-cooperative Nash equilibrium, all countries play pollute, i.e., $e_i = 1$. The model is set up as a standard two-stage game (following Barrett, 2001). In the first stage of the game, countries choose between joining and not joining an international coalition. In the second stage, the members of each coalition choose their level of emissions cooperatively in a simultaneous play game between all (given) coalitions and the outsiders.

First, let us look at the simplest case of one coalition. As usual, we proceed by backward induction, solving the second stage of the game first. In the case of one coalition with $k_1$ type-1 members and $k_2$ type-2 members, the outsiders all play pollute as a dominant strategy. We denote the aggregate emissions of all outsiders by $E^{out}$ and the number of polluting members of type $i$ with $k_i^p \leq k_i$. The joint payoff of the members of a coalition denoted by $J$ is thus

$$\Pi^J = \beta(k_1^p + k_2^p) - (\delta_1 k_1 + k_2)(k_1^p + k_2^p + E^{out}). \tag{3.1}$$

The members maximize their payoff $\Pi^J$ cooperatively with respect to $k_1^p, k_2^p$. Here and in the following, variables referring to a game equilibrium are denoted by $\cdot^*$. The linear payoff function implies the corner solutions

$$k_i^{p*} = \quad 0 \quad \text{(abate) if } \delta_1 k_1 + k_2 > \beta, \tag{3.2}$$

$$k_i^{p*} = \quad k_i \quad \text{(pollute) if } \delta_1 k_1 + k_2 < \beta. \tag{3.3}$$

For the first game stage, we determine stable coalitions (d'Aspremont et al., 1983). A coalition is stable if no outsider has an incentive to join (external stability) and no member has an incentive to leave (internal stability).

As playing pollute is a dominant strategy for outsiders, this condition is only fulfilled if the members choose to abate and would change to pollute if one member left the coalition. This happens if the withdrawal of one country would diminish the gains from cooperation for the remaining members so much that they would jointly change their strategy to pollute. We call such cases "linchpin" equilibria (cf. Barrett, 2001; Chander and Tulkens, 1995).

From condition (3.2) and (3.3), we see that $(k_1^*, k_2^*)$ represents a stable and abating coalition if condition (3.2) holds and if $\beta > \delta_1(k_1^* - 1) + k_2^* > \delta_1 k_1^* + (k_2^* - 1)$. Thus, internal stability for a single coalition is given if

$$\beta + \delta_1 > \delta_1 k_1^* + k_2^* > \beta. \tag{3.4}$$

Such a coalition is also externally stable because playing pollute is a dominant strategy for outsiders, so that an outsider has no incentive to join an abating and internally stable coalition.

It would be interesting to know the conditions under which only countries of the same type would join the coalition. According to (3.4), an abating coalition with only type-1 members ($k_2 = 0$) is possible for

$$\beta + \delta_1 > \delta_1 k_1^* > \beta, \tag{3.5}$$

and with only type-2 countries ($k_1 = 0$) if

$$\beta + 1 > k_2^* > \beta. \tag{3.6}$$

Conditions (3.4) to (3.6) show that a stable coalition could consist of either both types of countries or countries of only one type.

Now consider that we admit up to two parallel and disjoint coalitions that make their abatement decisions independently but cooperate internally. For expository reasons, we assume in this section that each coalition admits only countries of the same type (coalition 1 denoted by $J_1$ consists of $k_1$ type 1 countries and coalition 2 denoted by $J_2$ of $k_2$ type 2 countries; this assumption is relaxed in the next section). The aggregate payoff of coalition $J_i$ is

$\Pi^{J_i} = \beta k_i^p - \delta_i k_i (k_1^p + k_2^p + E^{out})$, which is maximized by the corner solution

$$k_i^p = \begin{cases} 0 & \text{(abate) if } \delta_i k_i > \beta, \\ k_i & \text{(pollute) if } \delta_i k_i < \beta. \end{cases} \tag{3.7}$$

Recall that $\delta_2 = 1$. We see that the decision of each coalition $S_i$ depends on the number of its members $k_i$ and on the benefits from emissions $\beta$, but not on the members of the other coalition.

The first stage of the game is solved by applying the criteria of internal and external stability in analogy to the case of one coalition. As the abatement decisions of the two coalitions are mutually independent, the conditions for both coalitions to be internally stable can be reduced to (3.5) and (3.6). As in the case of one coalition, the criterion of external stability is always satisfied because playing pollute is a dominant strategy for outsiders so that they have no incentive to join an abating coalition.

Finally, compare the equilibria with one and two coalitions. Denote a set of two stable and abating coalitions by $(k_1^{**}, k_2^{**})$. By adding (3.5) and (3.6), we find that

$$2\beta + \delta_1 + 1 > \delta_1 k_1^{**} + k_2^{**} > 2\beta. \tag{3.8}$$

For convenience, we use the notation $K^{**} := \delta_1 k_1^{**} + k_2^{**}$ to represent a measure for the total emissions abatement by all coalitions. We see from (3.4) and (3.8) that $K^{**} > K^*$, so we can summarize:

**Proposition 3.1.** *If the marginal benefits and damages of emissions are constant, the total number of abating countries in the case of two coalitions is greater than in the case of one coalition.*

Further, it is of interest to know whether two stable and abating coalitions are also intercoalition-stable, that is, whether they have no incentive to swap coalitions (cf. Osmani and Tol, 2010). If one member country of type $i$ would swap coalitions, the number of members $k_i$ would decrease by one, while the number of members of the other coalition would increase. We saw that a decrease in the number of members $k_i$ would change the decision of the remaining members from abate to pollute. As a consequence, the total number of abating countries would decrease from $k_i^{**} + k_j^{**}$ to $k_j^{**} + 1$. Every country would lose. Thus, intercoalition stability is guaranteed.

## 3.3 Multiple Climate Clubs with Non-linear Damages or Benefits

In the following sections, we analyze the more general case of $i \in I$ different types of countries that are admitted to be asymmetric in terms of both their benefits and damages of emissions. Countries are admitted to join one of multiple coalitions $J \in \mathcal{J}$, where $\mathcal{J}$ is a family of disjoint subsets of all countries. Each country of type $i$ has emissions $e_i \in [-\infty, \bar{e}_i]$ with $\bar{e}_i$ being its non-cooperative business-as-usual emissions. We thus admit negative emissions (which might be reasonable in the light of carbon capture and storage technologies), but not more emissions than could be produced given economic capacities in the non-cooperative business-as-usual scenario.

After introducing the basic assumptions and notation, the first subsection focuses on non-linear benefits of emissions, the second on non-linear damages from emissions, and the third on both non-linear benefits and damages from emissions. The number of type-$i$ members of coalition $J$ is denoted by $k_i^J$. Countries that do not join any coalition may simply be regarded as coalitions of size 1 as their choice of emissions is not relevant for the following argumentation. The amount of emissions of each coalition $J$ is characterized by the vector $e^J := (e_1^J, \dots, e_{|I|}^J)$, where $e_i^J$ is the quantity of emissions for each member country of type $i$ in coalition $J$. Total emissions are therefore given by $E := \sum_{i,J} k_i^J e_i^J$, whereas the total emissions of coalition $J$ are denoted by $E^J := \sum_i k_i^J e_i^J$, and the emissions all other countries by $E^{-J} := E - E^J$.

In the second stage, the members of each coalition choose their level of emissions cooperatively, simultaneous with all (given) coalitions and the outsiders. We denote the second-stage equilibrium emissions of all countries by $E^*(k_1^J, \dots, k_{|I|}^J)$. In the first stage of the game, countries choose between joining (exactly) one of the multiple coalitions or being an outsider. In this decision, they anticipate the effects on the second-stage game equilibrium.

### 3.3.1 Climate Clubs with Decreasing Marginal Benefits

In this section, we assume that the marginal benefits of emissions are decreasing, and that the marginal damages are constant. The latter is a common assumption in part of the literature (e.g. Pavlova and de Zeeuw, 2013; Beccherle and Tirole, 2011). The former assumption generalizes a typical quadratic or logarithmic formulation towards an arbitrary concave benefit function. The payoff for one country $i$ in coalition $J$ is

$$\Pi_i^J(e_i^J, E) = b_i(e_i^J) - \delta_i E, \tag{3.9}$$

with $b_i(e_i^J)$ being a differentiable, monotonically increasing concave function of the amount of emissions $e_i^J$ produced by the country $i$ in coalition $J$, and $\delta_i > 0$. The aggregated payoff for the members of coalition $J$ is therefore given by

$$\Pi^J(e^J, E) = \sum_i k_i^J b_i(e_i^J) - \sum_i k_i^J \delta_i E. \tag{3.10}$$

Then, the following propositions show that multiple coalitions can include a larger number of cooperatively abating countries in stable coalitions than a single IEA. The proof also shows that multiple individually stable climate clubs can coexist. If the countries in these stable coalitions were forced to join a single coalition, it would not be stable.

**Proposition 3.2.** *If the marginal benefits from emissions are decreasing and the marginal damages are constant, total emissions abatement increases with the number of individually stable coalitions.*

*Proof.* Each coalition $J$ maximizes $\Pi^J$ with respect to all members' emissions $e_i^J$ by taking the total emissions of all others $E^{-J}$ as given. The first-order condition for each country type $l$ in a coalition $J$ is

$$\frac{d\Pi^J}{de_l^J} = k_l^J b_l'(e_l^J) - \sum_i k_i^J \delta_i k_l^J = 0, \tag{3.11}$$

so that

$$\forall l \in I: \qquad e_l^J = b_l'^{-1}\left(\sum_i k_i^J \delta_i\right). \tag{3.12}$$

Thus

$$E^J = \sum_l k_l^J b_l'^{-1}\left(\sum_i k_i^J \delta_i\right), \tag{3.13}$$

does not depend on $E^{-J}$: Every coalition has a dominant strategy, making its own emission decision independently of the decisions of all other coalitions. Consequently, the internal and external stability conditions are not affected by any abatement decisions of outsiders of coalition $J$, i.e., the stability of coalition $J$ is independent of the existence of other individually stable abating coalitions. The maximum number of countries that are members of internally and externally stable coalitions increases with the number of coalitions.

If there exists at least one individually stable abating coalition satisfying internal and external stability with $\sum_i k_i^J > 1$, and if there are enough countries to form a further individually stable abating coalition, they will do so. Their emissions abatement will be additional to other countries' abatement amounts, without causing existing coalitions to increase their emissions. □

The question of abatement in our case thus boils down to the existence of at least one individually stable coalition, and it can be answered positively: With asymmetric countries, linear damages, and concave benefits from emissions, it is known that an internally and externally stable coalition exists (e.g. Bauer, 1992; Fuentes-Albero and Rubio, 2010; Pavlova and de Zeeuw, 2013). We can also show an additional property:

**Corollary 3.1.** *If multiple internally and externally stable coalitions exist, these coalitions are intercoalition-stable.*

*Proof.* Whenever a country has neither an incentive to leave its coalition and become a free-rider (internal stability) nor an incentive to join another existing coalition (from its potential position as a free-rider, external stability), it would not switch coalitions as this would combine the two unprofitable decisions into one even more disadvantageous step. Note that this argument only works since damages are linear. □

The results obtained in this subsection can be roughly summarized as follows. With any concave benefits from emissions and constant marginal damages, each coalition makes an independent decision on its emissions. Some countries prefer a stable coalition (of a size larger than one member) to reap some benefits of cooperation. We know from the existing literature that such stable coalitions tend to be small. If additional countries joined such a coalition, the benefits of cooperation would diminish. However, countries that are not part of an existing coalition may be willing to form another small coalition with larger benefits from cooperation. Due to the dominant strategies, these benefits are not affected by the number of countries that are already members of other stable coalitions. Thus, as long as there is at least one set of countries left that would form a stable coalition (even if there were no other coalitions), these countries would cooperate, leading to emissions abatement that is additional to that of other coalitions.

### 3.3.2 Climate Clubs with Increasing Marginal Damages

We now assume constant marginal benefits from emissions and increasing marginal damages. The former is common in some strands of the literature (c.f. Marrouch and Ray Chaudhuri, 2016), while the latter assumption generalizes a typical quadratic formulation towards an arbitrary convex damage function. The payoff of a country $i$ in coalition $J$ thus depends on the total emissions and on its own decision according to

$$\Pi_i^J(e_i^J, E) = \beta_i e_i^J - f_i(E), \tag{3.14}$$

with $f_i(E)$ being a differentiable, monotonically increasing convex function of the total emissions $E$, $0 \leq e_i^J \leq \bar{e}_i$, with $\beta_i > 0$, $f_i'(\bar{E}) < \beta_i$ and $f_i(0) = 0$. This implies $e_i = \bar{e}_i$ as a dominant strategy for outsiders. Denote $\bar{E} := \sum_{i,J} k_i^J \bar{e}_i{}^J$. We restrict our attention to those settings where

$$\exists l, E < \bar{E} : \sum_{i,J} k_i^J f_i(E) \geq \beta_l E, \tag{3.15}$$

meaning that there is at least some emissions abatement in the fully cooperative case. Otherwise, our whole investigation would be pointless. The aggregate payoff of a coalition $J$ is given by

$$\Pi^J(e^J, E) = \sum_i k_i^J \beta_i e_i^J - \sum_i k_i^J f_i(E). \tag{3.16}$$

We obtain a result under these conditions that is in stark contrast to the case with constant marginal damages.

**Proposition 3.3.** *If marginal benefits of emissions are constant and marginal damages are increasing, total emissions will be identical for both one and multiple coalitions.*

*Proof.* Define the functions $g_J$ implicitly by $E = g_J(\sum_i k_i^J f_i'(E))$. Then the first-order conditions for the optimal emission decision of coalition $J$ yield

$$\forall i : E = g_J(k_i^J \beta_i). \tag{3.17}$$

Total differentiation of the first-order conditions also yields

$$\forall i : \frac{dE}{dk_i^J} = -\frac{f_i'(E)}{\sum_l k_l^J f''(E)} < 0. \tag{3.18}$$

Total emissions can be expressed as $E^J + E^{-J} = E = g_J(k_i^J \beta_i)$, so that the best response function of coalition $J$ is given by

$$E^J = g_J(k_i^J \beta_i) - E^{-J}. \tag{3.19}$$

Recall that countries that are not members of any coalition dominantly choose emissions $\bar{e}_i$. The best response function has a slope of $-1$. Every unit of emissions that is reduced by one coalition will be followed by one unit of additional emissions from another coalition. Thus, total emissions do not depend on the number of existing coalitions. □

The proposition shows that considering multiple climate clubs does not lead to any additional abatement. While the previous results in this chapter hold without any assumptions on burden-sharing, the existence of a stable coalition with constant marginal benefits of emissions and increasing marginal damages rests on a burden-sharing rule of the coalition. In the following we therefore assume proportional burden-sharing, meaning that the burden of foregone benefits becomes proportional to the members' benefits of reduced damages. The countries $i^*$ with the smallest $\beta_i$ within each coalition reduce their emissions as indicated by the joint decision and are refunded for their foregone benefits by the countries with higher marginal benefits of emissions.

We now turn to the existence of at least one stable coalition that reduces emissions. As all outsiders dominantly play $\bar{e}_i$, the total emissions are de facto determined by the decision of the coalition. Let $E^*$ be the total emissions chosen by coalition $J$ of which country $l$ is a member, and $\Pi_l^J$ the payoff of country $l$ in this situation. Let $E^{*-l}$ be the amount of total emissions if country $l$ leaves the coalition, and $\Pi_l^-$ the associated payoff.

**Proposition 3.4.** *Assume asymmetric countries, convex damages, and linear benefits from emissions. Then, with proportional burden-sharing, an abating and internally stable coalition exists.*

*Proof.* First, condition (3.15) implies that at least in the fully cooperative case the coalition abates some emissions. The question is whether an abating coalition is internally stable. The total amount of emissions $E^*$ increases with decreasing coalition size due to (3.18).

We show in the following that internal stability is achieved when the coalition size represents a linchpin equilibrium. We can be sure that such an equilibrium exists since a coalition of size 1 (a single country) dominantly plays $\bar{e}_i$. The coalition at the linchpin equilibrium is characterized by

$$\forall l : E^* < \bar{E} \text{ and } E^{*-l} = \bar{E}. \tag{3.20}$$

Each country leaving would cause the remaining members to switch to $\bar{E}$ as joint payoff-maximization does not incentivize emission reductions. The members in the linchpin equilibrium are better off by jointly deciding to reduce emissions to $E^*$, i.e., $\Pi^J(E^*) > \Pi^J(\bar{E})$. If all members share the burden of foregone benefits of emissions proportionally to their benefits of reduced damages, no country has an incentive to leave the linchpin-coalition. □

We can further show that there is no incentive to form two or more coalitions: As the members can jointly decide which of them have to undertake the emission reductions (and then be refunded by the others), this will be done by those countries $i^*$ with the smallest $\beta_i$ within each coalition. Thus every coalition has only one condition to fulfill:

$$E = g_J(\beta_{i^*} k_{i^*}^J). \tag{3.21}$$

If we exclude the boundary case with two coalitions having exactly the same $\beta_{i^*}$, this implies two contradicting conditions for the same variable $E$. Any club of countries would free-ride if another one already abates.

To sum up, this section shows that in case of linear benefits and convex damages, total emissions cannot be reduced by increasing the number of admitted coalitions to more than one. By virtue of the general formulation of the model in Sec. 3.1 and Sec. 3.2, the results include the special cases of symmetric countries, but also hold for countries that are asymmetric in their benefits and damages of emissions. Thus, these results are more general than previous findings in studies with symmetric countries (e.g. Yi, 1997; Ray and Vohra, 2001; Bloch, 2003; Finus and Rundshagen, 2006; Asheim et al., 2006) or simulation studies (e.g. Osmani and Tol, 2010; Bosello et al., 2003; Eyckmans and Finus, 2006).

### 3.3.3 Clubs with Increasing Marginal Damages and Decreasing Marginal Benefits

The results of the sections above hold for rather general conditions for either damages or benefits, but restrictive conditions for the other variable. These two cases lead to opposing results: admitting clubs leads either to no advantage at all or to an extreme advantage. Thus, if both damages and benefits are non-linear, we might expect results that lie in between. We are yet not able to analytically solve the most general situation in which each country is different from the others and may have any convex damage and any concave benefit function. We thus explore in the following a case with a specific parametrization of asymmetric countries to discuss the scope and limits of clubs. First the specific game is introduced and some general notation and features of clubs are described. We use this to compare the situations of one and two stable clubs, and illustrate it with a numerical example.

Let $N$ denote the set of all countries. The payoff of each country $n \in N$ follows e.g. Barrett (1994) and Diamantoudi and Sartzetakis (2006) with quadratic damages and benefits, $\Pi_n(e_n, E) = b_n(\bar{e}_n e_n - \frac{1}{2}e_n^2) - \frac{1}{2}c_n E^2$, where each country can have idiosyncratic parameters $\bar{e}_n, b_n, c_n \geq 0$. Define $e_{-n} = E - e_n$. For convenience, we further define $a^S := \sum_{n \in S} \bar{e}_n$ for any subset of countries $S \subseteq N$. Let $\gamma_n := \frac{c_n}{b_n}$ and $\gamma^S := \sum_{n \in S} \gamma_n$. Finally, define $\gamma_n^l := \frac{c_l}{b_n}$ and $\gamma_S^S := \sum_{n,l \in S} \gamma_n^l > \gamma^S$. We first collect some helpful features of the emissions game. It is known that the single countries' first-order conditions lead to

$$e_n = \frac{\bar{e}_n b_n - c_n e_{-n}}{b_n + c_n} = \frac{\bar{e}_n}{1 + \gamma_n} - \frac{\gamma_n}{1 + \gamma_n} e_{-n} = \bar{e}_n - \gamma_n E. \tag{3.22}$$

Now determine the aggregate emissions of a coalition $J$, supposing that the emissions of all countries that are not members of the coalition are given, i.e., the coalition's reaction function. We need to determine $\max_{e_n, n \in J} \Pi^J = \sum_{n \in J} \Pi_n(e_n, E)$, where the first-order conditions yield for all $n \in J$ the implicit characterization

$$\begin{aligned} e_n &= \bar{e}_n - \sum_{l \in J} \frac{c_l}{b_n}(E^J + E^{-J}), \\ E^J &= \sum_{n \in J} e_n = a^J - \gamma_J^J E. \end{aligned} \tag{3.23}$$

Note that the implicit characterization of this aggregate's reaction function has the same structure as that of single countries (3.22), except that emissions and parameters are replaced by the appropriate aggregates.

It is also possible to express the aggregate emissions $E^{NC}$ of a group of countries $NC \in \mathcal{J}$ that play non-cooperatively (among one another) for given aggregate emissions of other countries $E^{-NC}$. Each non-cooperative country decides according to (3.22). Thus

$$E^{NC} = \sum_{n \in NC} e_n = \sum_{n \in NC} \bar{e}_n - \gamma_n E = a^{NC} - \gamma^{NC} E. \tag{3.24}$$

As before, the linear structure from single countries or coalitions is retained, but note the difference in the coefficients $\gamma^{NC}$ that do not account for external effects. Again, this can be solved explicitly to obtain the reaction function by

$$E^{NC} = \frac{a^{NC}}{1 + \gamma^{NC}} - \frac{\gamma^{NC}}{1 + \gamma^{NC}} E^{-NC}. \tag{3.25}$$

Now, after these preparations, let us turn to the analysis of climate clubs. Assume that there are up to two disjoint coalitions $J, K \in \mathcal{J}$ (whether they are stable or not). Does this reduce emissions compared to the case with just a single coalition $J$ or $K$ (as in the case with linear damages), or not (as in the case with linear benefits)?

Let there be a third group of outsiders $NC$ with $NC \cup J \cup K = N$. Without any coalition, the non-cooperative Nash equilibrium is characterized according to (3.25) by

$$E = \frac{a^N}{1 + \gamma^N}. \tag{3.26}$$

In the case of a single coalition $J$, (3.23) characterizes the members' aggregate reaction function, while (3.24) characterizes the outsiders' $K \cup NC$ aggregate reaction function by $E^{K \cup NC} = a^{K \cup NC} - \gamma^{K \cup NC} E$. The game equilibrium is thus characterized by

$$E = E^J + E^{K \cup NC} = a^N - (\gamma_J^J + \gamma^{K \cup NC}) E, \tag{3.27}$$

so that total emissions become

$$E = \frac{a^N}{1 + \gamma_J^J + \gamma^{K \cup NC}}. \tag{3.28}$$

There are less emissions in this case than in the non-cooperative Nash equilibrium (3.26) since the denominator is larger. Now suppose that, in addition to $J$, the coalition $K$ also forms.

**Proposition 3.5.** *If damages and benefits of emissions are quadratic, the existence of two parallel climate clubs leads to a lower level of global emissions than the case in which only one of these clubs is admitted.*

*Proof.* We use the implicit characterization of three aggregate reaction functions from (3.23) and (3.24) to obtain

$$E = E^J + E^K + E^{NC} = a^N - (1 + \gamma_J^J + \gamma_K^K + \gamma^{NC})E. \tag{3.29}$$

Since $\gamma_J^J + \gamma_K^K + \gamma^{NC} > \gamma_J^J + \gamma^{K \cup NC}$, total emissions are smaller than (3.28). □

If we extend this proposition to more than two stable clubs, each additional club would further reduce emissions, but it would reduce them less than the previous new club did. This case is thus, as expected, between the two extreme cases considered in Sec. 3.1 and Sec. 3.2.

The last results leave aside the question of whether two stable climate clubs can exist in parallel. It only makes sense to ask this question if there are at least five countries and at least two country types. Then each coalition's conditions for internal, external, and intercoalition stability make up a list of six inequalities with rational functions that are difficult to interpret.

| No. | $J$ | $K$ | $NC$ | $\Pi_1$ | $\Pi_2$ | $\Pi_3$ | $\Pi_4$ | $\Pi_5$ | $E$ |
|---|---|---|---|---|---|---|---|---|---|
| (0) | $\cdot$ | $\cdot$ | $N$ | -.55 | -.55 | -.90 | -.90 | .50 | 6.65 |
| (1) | $\{1,2\}$ | $\{3,4\}$ | $\{5,\ldots,8\}$ | **-.34** | **-.34** | **-.70** | **-.70** | **.50** | 5.69 |
| (2) | $\{1,2\}$ | $\cdot$ | $\{3,\ldots,8\}$ | -.53 | -.53 | **-.73** | -.73 | .50 | 6.22 |
| (3) | $\cdot$ | $\{3,4\}$ | $\{1,2,5,\ldots,8\}$ | -.35 | **-.35** | -.86 | -.86 | .50 | 6.05 |
| (4) | $\{1,2,3\}$ | $\cdot$ | $\{4,\ldots,8\}$ | -.43 | -.43 | **-.74** | -.42 | .50 | 5.38 |
| (5) | $\cdot$ | $\{2,3,4\}$ | $\{1,4,\ldots,8\}$ | -.12 | **-.42** | -.73 | -.73 | .50 | 5.25 |
| (6) | $\{1,2,5\}$ | $\{3,4\}$ | $\{6,\ldots,8\}$ | -.22 | -.22 | -.55 | -.55 | **.36** | 5.31 |
| (7) | $\{1,2\}$ | $\{3,4,5\}$ | $\{6,\ldots,8\}$ | -.20 | -.20 | -.52 | -.52 | **.30** | 5.24 |

**Table 3.1:** Numerical example of stable coalitions with $b_1 = b_2 = 1.2, \forall n = 3,\ldots,8 : b_n = 1.0, c_1 = c_2 = 0.05, c_3 = c_4 = 0.06, \forall n = 5,\ldots,8 : c_n = 0.0$. Payoffs that need to be compared to assess stability (without loss of generality) are in bold face. For reference, No. (0) is the non-cooperative equilibrium, and No. (1) the coalition structure we want to asses. Numbers (2) and (3) confirm the internal stability of $J$ and $K$, respectively. Numbers (4) and (5) confirm intercoalition stability, while No. (6) and (7) external stability. Payoffs for countries $\{6,7,8\}$ are not written, as these have identical payoffs to those of country 5 (except in Numbers (6) and (7), where they are irrelevant for comparison).

Here we want to provide one numerical example for our game structure. Suppose there are eight countries $N = \{1,\ldots,8\}$, all with $\bar{e}_n = 1$, two countries $1,2$ with comparatively larger benefits from emissions, two countries $3, 4$ with comparatively larger damages, while the four remaining countries only suffer negligible damage. Table 3.1 shows that the coalition structure $J = \{1, 2\}, K = \{3, 4\}, NC = \{5, \ldots, 8\}$ is stable and leads to less emissions than structures with just the club $J$ or $K$. The example also shows that other structures with just one coalition may perform better in terms of emission reductions, but those cases in the example are not internally stable.

This subsection thus shows that in the case of increasing marginal damages and decreasing marginal benefits, two stable clubs can exist in parallel. It is possible that they abate, in total, more than if only one club is admitted.

## 3.4 Conclusions

This chapter has analyzed the case of multiple disjoint IEAs when there are asymmetric countries. In a two-stage game, countries first choose whether to sign exactly one agreement or to be an outsider. In the second stage, each coalition acts as a unitary actor in a non-cooperative simultaneous play game between the coalitions and the outsiders. We compare emissions abatement and coalition stability in the multiple IEAs case with the standard case, in which at most one IEA is possible. We investigate this for constant as well as increasing marginal damages from emissions and for constant as well as decreasing marginal benefits of emissions.

For constant marginal damages, multiple coalitions lead to lower global emissions and to a larger number of cooperating countries in multiple "climate clubs". Interestingly, this effect does not depend on the shares of the country types within the set of all countries in the game. These results follow from the dominant emission strategies of the coalitions. A coalition is stable if all countries would choose to pollute, if one more country left the coalition. This effect is replicated for each coalition. Thus multiple coalitions are stabilized with lower emissions than just one. When marginal damages increase and marginal benefits are constant, this picture changes dramatically. As there is no equilibrium structure with more than one abating stable coalition in the second stage, only one coalition will abate emissions cooperatively. All other countries would refrain from cooperation regardless of their potential membership in another coalition. Therefore, the possibility of multiple agreements does not lead to improvements compared to the case with only one agreement. With both convex damages and concave benefits of emissions, an extension of a standard parametrization towards asymmetric countries provides results in between these extreme cases. We find that the existence of two stable parallel climate clubs leads to a lower level of global emissions than the existence of only one coalition. A numerical experiment shows that two stable coalitions can exist.

The comparison of the different cases shows that the effect of climate clubs substantially depends on qualitative properties of the benefit and damage functions, even if they are quite simple. In this general sense, our results are in line with the ambiguous results in the examples of Osmani and Tol (2010). In contrast, however, we can generally show for our assumptions that climate clubs are at least not detrimental to global cooperation. It would require further investigation to determine whether the positive effects shown by, e.g., Asheim et al. (2006) and Bauer (1992) stem mainly from the constant marginal damage assumption. Nevertheless, our results need to be taken with caution. Although our analysis is more general than single numerical examples, the analytical results reach their limits when both benefits and damages are nonlinear. It is then unclear whether parallel and stable climate clubs with more abatement than in the standard case always exist. This calls for further generalization.

On the other hand, the chapter already shows how the shape of costs and benefits leads to quite different prospects of climate clubs. We think that our analysis thus offers an important stepping stone towards a more detailed understanding of the determinants of beneficial or detrimental effects of climate clubs. In any case, we must conclude that the idea that climate clubs do benefit global climate protection has to be taken with caution, but that it deserves more analytical attention. Our results show that the idea of climate clubs points in useful directions for further research. Allowing for overlapping coalitions with countries that are members of more than one coalition could provide further insights. Apart from that, issue linkage is discussed in the literature on climate clubs (e.g. Weischer et al., 2012; Widerberg and Stenson, 2013) and would offer an interesting field for further game theoretic analysis. The design of different transfer mechanisms, intra- and inter-coalitional, is a further extension of the analysis that could provide insights for a more effective climate regime. Finally, the timing in the emissions game could be changed to a sequential Stackelberg game with one coalition moving before the other, or the timing might even be endogenized (cf. Heugues, 2012; Eisenack and Kähler, 2015).

# 4 | The Influence of Political Pressure Groups on the Stability of IEAs

## 4.1 Introduction

Game theoretical studies on the formation and stability of IEAs have pointed out that strong free-rider incentives exist and that these prevent agreements from being effective (e.g. Hoel, 1992a; Carraro and Siniscalco, 1993; Barrett, 1994, 1997b; Jeppesen and Andersen, 1998).[4] A common characteristic of these studies is that the participants in international negotiations are treated as monolithic and benevolent governments that truly represent the common interests of their nations.[5] Furthermore, it is assumed that governments only care about the aggregated welfare level of their respective country. Thus, in this view, welfare maximization is the main force that drives environmental policy decisions. However, recent events in the international policy arena have illustrated the fact that national political actors (e.g. lobby groups and voters) are able to affect environmental policy-making, both at the national and the international level.[6]

Even though the game theoretical analysis of IEAs has yielded many important insights, it has so far largely ignored the fact that governments often have interests not in line with those of their constituency. Moreover, it has not been considered in this literature that the electoral process and the lobby groups may influence what governments would do at the international negotiation tables. In particular, lobby groups (e.g. business associations and environmental NGOs) may be able to affect the behavior of politicians by providing information, by financing election campaigns, or by bringing environmental concerns to the forefront of the minds of the

[4] This chapter is based on Hagen et al. (2016).

[5] Chapter 2 and Wangler et al. (2013) argue for extending the game theoretical analysis of IEAs to consider actors that are not nation state governments.

[6] Although there are some corporations that support the US climate agenda adopted during Obama's presidency, e.g. Mars, Ikea, Kellogg's and Unilever, these are outnumbered by the efforts of powerful lobbies like the US Chamber of Commerce and the National Association of Manufacturers and the many lobbyists from the coal, oil and natural gas industries (Gunther, 2015). Only recently, in 2015, the oil company BP announced that it will stop funding the American Legislative Exchange Council, a lobbying group that presented biased reports about climate science to US state legislators (Frumhoof and Oreskes, 2015).

voters (Grossman and Helpman, 2001). These political factors play an important role when the national representatives meet at the international level and will in turn impact the decision whether or not to participate in an IEA.

Most of the studies on the influence of interest groups on policy-making focus on the role of producer groups in the determination of trade policies. In this area, the political contributions approach of Grossman and Helpman (1994, 1995, 1996) is a standard model. Grossman and Helpman study the effect of lobby contributions on trade policies. They consider self-interested policy-makers who seek to maximize the sum of lobby contributions and the welfare of the median voter in order to increase their chances to be reelected. The political contributions approach has further been applied to study environmental policy-making (e.g. Fredriksson, 1997; Aidt, 1998; Conconi, 2003; Fredriksson et al., 2005; Aidt and Hwang, 2014; Batina and Galinato, 2014). Fredriksson (1997) shows that there is a relation between the strength of lobby activities and the deviation from an optimal pollution tax. Aidt (1998) explains that lobby groups, through the competitive political process, are important to internalize production externalities. Conconi (2003) shows that the impact of lobby groups on environmental policy depends on the trade policy regime and the size of the transboundary environmental spillovers. Fredriksson et al. (2005) report empirical evidence for OECD countries that there is an effect of lobby actions on policy-making and that it is more likely to occur in countries with sufficiently high levels of political competition. Aidt and Hwang (2014) study the effects of foreign lobbying on another country's welfare; they find that lobby efforts, as a means of political internalization of cross country externalities, only maximize global social welfare under very restrictive assumptions but usually inefficiencies prevail. Batina and Galinato (2014) describe the tradeoffs between the influence of the environmental damage caused by the resource extraction and the contributions received from lobbies, when these contributions affect a government's tax and expenditure policies in the presence of tax competition with other governments. Empirical work by Fredriksson et al. (2007) shows that the ratification of the Kyoto Protocol has been facilitated by environmental lobbying in particular in countries with a lower integrity of government. Altamirano-Cabrera et al. (2007) have studied the impact of lobby groups on the stability of climate agreements in a empirically calibrated simulation model. They find that although lobby contributions may help to stabilize IEAs the additional greenhouse gas abatement is insignificant. Anger et al. (2015) use a theoretical and empirical framework to assess the effect of lobbies on emission allowance allocations under the EU emissions trading scheme (ETS). They find that because of lobbying of energy-intensive firms within the ETS, the regulatory burden of emission abatement is shifted to non-ETS sectors that might be subject to inefficiently high emission taxes.

There are few examples of theoretical studies that combine an analysis of the influence of interest groups (e.g. using the political contributions approach) with an analysis of the stability of IEAs. Such combined approach is adopted, for instance, by Soo-Kim (2013) who analyzes, in a two-country, two-goods model, the conditions under which politically viable IEAs could evolve; he finds that two critical factors for viable IEAs are the price elasticity of supply and the weight the politicians place on the general welfare versus lobby contributions. Closest to this chapter is the work by Haffoudhi (2005) and Marchiori et al. (2017) who have studied the impact of lobby groups on the size and stability of IEAs for homogeneous countries. Haffoudhi (2005) finds that a global agreement would be sustained by means of industry lobby contributions. Similarly, Marchiori et al. (2017) find that a strong industry lobby may increase the incentives of the government to participate in an agreement. This result is driven by the assumption that the government can commit to a stricter abatement policy by joining the IEA and thereby collect larger lobby contributions from industry.

This chapter extends this work. As in Grossman and Helpman (1994), we assume that lobbies try to influence government's policy decisions and we abstract from the election process. We represent lobbies' influence as prospective contributions that enter into the government's political revenue function and are made conditional on a change of government's policy decisions. Different from Haffoudhi (2005) and Marchiori et al. (2017), we relax the assumption that countries are symmetric. We allow for different lobby strength in different countries. This allows us to study impacts of changing lobby strength in a particular country on the stability of an IEA. For that we employ the concept of internal and external stability (d'Aspremont et al., 1983).

The formation of IEAs is modeled as a game in which governments decide about their participation before they choose their abatement strategies - considering both net benefits from abatement and the prospective lobby contributions. We assume that there are two lobbies from which governments can obtain contributions: industry and environmentalist. We consider that the level of contributions depends on each lobby's payoff function and the abatement strategy chosen by the government. The payoff of an environmentalist lobby depends on the additional abatement efforts undertaken. We assume that the industry lobby is always harmed if the government increases abatement. Our results show that the influence of lobby-groups has an effect on the abatement decisions of the respective countries. This influence can be observed for members of an IEA as well as for outsiders. However, in the case of IEA-members, the effects of lobbying are not restricted to the lobby's host-country but spill over to other member countries and have ambiguous effects on the IEA-stability.

First, we lay out our model and explain the stages of the game. We then solve the game by backward induction and focus on the abatement decisions of the countries and the stability of the IEA before the chapter concludes with a summary and discussion.

## 4.2 Description of the Model

We study the impact of lobbying on the formation and stability of IEAs in a sequential game. The players in our game are lobbies and governments in $n$ countries. The set of countries is denoted $N$. An IEA is a subset of all countries $S \subseteq N$. Our game starts with (1) the announcements of the lobby-contributions. This is followed by the workhorse model of IEA formation with two stages (2) governments' participation decision and (3) the transboundary pollution game. Finally, (4) lobby contributions are paid according the announcements at stage 1. We describe these stages in more detail in turn.

### 4.2.1 The Announcement of the Lobby-Contributions and Formation of an IEA

Lobbying takes place in all countries $i \in N$ and affects national policies. In our model the policy space is the level of abatement, reflecting the strictness of the environmental policy adopted. Hence, a particular policy is described by a variable $q_i \in [0, \bar{e}_i]$ , where index $i$ refers to an individual country and $\bar{e}_i$ is the level of business-as-usual emissions of a country. We denote the policy of a signatory country $i \in S$ by $q_i^s$ and the policy of $i \in N \setminus S$, an outsider, by $q_i^{out}$. Following a common assumption in the literature (c.f. Grossman and Helpman, 1996; Aidt, 1998; Conconi, 2003), we assume two exogenously given lobby groups, (i) the industry, referred to as "firms" $f$, and (ii) the environmentalists, referred to as "greens" $g$. The firms' preferred policy is $q_i = 0$, i.e. their preferred level of abatement is zero as this avoids abatement costs. By contrast the greens' preferred policy is full abatement, i.e. $q_i = \bar{e}_i$. Hence both lobbies pull in opposite directions. The government maximizes a political revenue function that reflects social welfare and the influence of lobby groups. We model lobby pressure as prospective contributions that reflect the willingness to pay of a lobby to influence the government's policy decisions in their favor.

Contributions represent the monetary value assigned to all lobbying activities that influence the government's decisions.[7] The political revenue function thus has two components. First, it is a function of a country's net benefits from the climate policy adopted. This may include the net benefits resulting from participating in an IEA. Second, political revenue depends on the contributions from lobby groups.

The political revenue function of the government in country $i$, $\pi_i$, reflects the benefits and costs of greenhouse gas abatement and the prospective contributions, $L$, from lobby groups

[7] Some authors argue that contributions may be interpreted as bribes in order to influence government policies (see Schulze and Ursprung, 2001).

supporting the government's policy. The political revenue function is

$$\pi_i(q_i, q) = B_i(q) - C_i(q_i) + \lambda_i L_i(q_i, q) \tag{4.1}$$

where $B_i(q)$ are the total benefits from global abatement denoted by $q = \sum_{i \in N} q_i$, and $C_i(q_i)$ are the total abatement costs from own abatement $q_i$. We assume that $B_i(q)$ is concave, i.e. $\frac{\partial B_i}{\partial q} > 0$ and $\frac{\partial^2 B_i}{\partial q^2} \leq 0$, $C_i(q_i)$ is strictly convex, i.e. $\frac{\partial C_i}{\partial q_i} > 0$ and $\frac{\partial^2 C_i}{\partial q_i^2} > 0$. The parameter $\lambda_i$ captures the relative weight of contributions compared to net benefits from abatement. Finally, $L_i(q_i, q) \geq 0$, represents the total contributions from local lobbies. Total lobby contributions are the sum of firms' and greens' contributions, $L_i(q_i, q) \equiv L_i^f(q_i) + L_i^g(q)$ with firms' contributions $\frac{\partial L_i^f}{\partial q_i} < 0$ and $\frac{\partial^2 L_i^f}{\partial q_i^2} < 0$ and greens' contributions $\frac{\partial L_i^g}{\partial q} > 0$ and $\frac{\partial^2 L_i^g}{\partial q^2} \leq 0$. Lobby contributions will be further specified below.

In the first stage lobby groups announce their prospective contributions to their countries' governments that are contingent on the governments' abatement decisions. At stage 2 all countries $i \in N$ decide simultaneously whether or not to join an IEA. We denote a country $i$'s choice to join and become a signatory by $\sigma_i = 1$. If country $i$ does not join, $\sigma_i = 0$, it remains a singleton player. The signatories $S \subseteq N$ act jointly at stage 3, i.e. they act like a single player in the subsequent transboundary pollution game. If no country or only a single country joins the IEA, then there is no effective agreement. We refer to this situation as "'All Singletons" and denote it by $S = \emptyset$. If $S = N$, we have the Grand Coalition. We assume that signatories make a binding agreement. Hence, we restrict our attention to participation and do not discuss enforcement.[8]

### 4.2.2 The Transboundary Pollution Game and Payment of the Lobby-contributions

Our model of transboundary pollution is standard in the literature and has been used in recent contributions (e.g. Asheim and Holtsmark, 2009). We consider a uniformly mixing pollutant (such as greenhouse gases). In this setting, abatement is a pure public good. At the abatement stage the IEA has been formed and, as indicated before, we assume that it behaves like a single player. Hence the players of the transboundary pollution game are the IEA and the remaining singletons. Each non-signatory government chooses abatement to maximize its political revenue given by (4.1). To arrive at closed form solutions we assume that benefits are linear and costs are quadratic in abatement. Further we aim to focus our study on the effects of lobby-groups on governments' abatement and participation decisions and therefore assume in the following that countries are symmetric in their direct costs and benefits from abatement but

[8] McEvoy and Stranlund (2009) and Yu (2017, Ch. 5) introduce models that address both issues.

governments attach different relative weights to contributions. Thus we have

$$\pi_i(q_i, q) = bq - \frac{1}{2}c{q_i}^2 + \lambda_i L_i(q_i, q). \tag{4.2}$$

Signatory governments cooperatively decide about their abatement to maximize the joint payoffs, including lobby contributions. The abatement decisions are taken in a simultaneous-move game. After the governments have decided about their emissions abatement, payoffs are determined on the basis of abatement costs and benefits, and lobby groups pay the contributions according to their announcements. Given our specifications this game has a unique Nash equilibrium.

## 4.3 Emission Abatement

The game is solved by backward induction. We start the analysis at the last stage of the game. At this stage, lobbies pay their contributions depending on the abatement decisions of the countries. Lobbies are committed to the contribution schedules announced in the first stage of the game. Here the analysis can draw on results by Bernheim and Whinston (1986) who have shown that lobby-groups do not lose by announcing truthful contribution schedules. A truthful contribution schedule is one that reflects the gains of a lobby from influencing the government's policy decisions in their favor. In our game firms gain from lower abatement as they save costs; environmentalists gain from higher (global) abatement as pollution damages are reduced. Thus the lobby contributions can be described as follows.
Firms in country $i$ face additional abatement costs. They bear a fraction $\phi_i$ of these costs while a fraction $1 - \phi_i$ is passed on to consumers. Hence we stipulate that firms' willingness to pay for reducing abatement is given by

$$L_i^f(q_i) = \hat{L}_i^f - \phi_i \frac{1}{2} c{q_i}^2 \tag{4.3}$$

where $\hat{L}^f$ denotes the contribution that firms are willing to make if their preferred policy option $q_i = 0$ is adopted.[9] The greens appreciate any avoided damage from emissions, i.e. the benefits of abatement. Their willingness to pay for additional abatement is as follows

$$L_i^g(q) = \gamma_i q \tag{4.4}$$

[9]Other assumptions for the firms are also possible and do not change the results as long as both lobby groups choose to pay lobby contributions and we have an interior solution. Since we observe both environmentalists' and firms' lobbying activities in the international policy arena this seems to be a reasonable assumption.

where $\gamma_i$ is a scaling parameter that captures the greens' preference for money vis-à-vis the avoided damage. In contrast to the firms the greens offer contributions that depend on global abatement as they are concerned with damages from pollution. We consider only positive lobby contributions (c.f. Habla and Winkler, 2013) so that lobbies are not compensated for potential losses from the government's decisions.

In the third stage of the game the amount of emissions abatement is chosen. All non-signatories maximize their political revenue functions simultaneously with the signatories' joint decision. Maximization of (4.2) yields the non-signatories' abatement decision dependent on the lobby-contributions proposed in the first stage:

$$q_i^{out} = \frac{b + \lambda_i L_i'(q_i^{out}, q)}{c}. \tag{4.5}$$

The signatories of the IEA coordinate their environmental policies to maximize the joint political revenues of the governments involved $\pi^S(q_i^s, q)$, i.e.

$$\pi^S(q_i^s, q) = \sum_{i \in S} \pi_i(q_i^s, q) = \sum_{i \in S} [bq - \frac{1}{2}c(q_i^s)^2 + \lambda_i L_i(q_i^s, q)]. \tag{4.6}$$

The solution of this maximization problem yields the abatement decision for each member country $i$ dependent on the lobby contributions

$$q_i^s = \frac{\sum_{j \in S} (b + \lambda_j L_j'(q_j^s))}{c}. \tag{4.7}$$

Inserting (4.3) and (4.4) in (4.5) gives the quantities of emissions abatement that are undertaken by outsiders

$$q_i^{out} = \frac{b + \lambda_i \gamma_i}{c(1 + \lambda_i \phi_i)}. \tag{4.8}$$

We see that non-signatories have dominant abatement strategies that do not depend on the number of IEA-signatories nor on the abatement of others. The quantities of emission abatement of a signatory country $i$ can be found by inserting (4.3) and (4.4) in (4.7) and reads

$$q_i^s = \frac{\sum_{j \in S} (b + \lambda_j \gamma_j)}{c(1 + \lambda_i \phi_i)}. \tag{4.9}$$

Comparing (4.8) and (4.9) we directly see that signatories abate a larger amount of their emissions than the non-signatories assuming the strength of lobby contributions is the same across countries.

**Proposition 4.1.** *The inclusion of lobby groups has an effect on the optimal abatement quantities of signatories and non-signatories. (1) The inclusion of firms' lobby contributions in any country $i \in N \setminus S$ results in lower abatement in that country. (2) The inclusion of green lobbies in country $i \in N \setminus S$ results in higher abatement in that country. (3) In signatory countries green lobbying has a spillover effect on abatement decisions in all other signatory countries, i.e. other signatories abate more as a response to green lobby contributions in some member country $i$.*

*Proof.* Appendix 4.6.1. □

Already at this stage we see from part (1) of Proposition 4.1 that lobby groups influence global emissions abatement in the "All Singletons" situation with $S = \emptyset$ and in the case of partial coalitions $S \subseteq N$ . While the presence of greens leads to a larger amount of globally abated emissions, firms' lobbying reduces global efforts to mitigate climate change. From part (3) of Proposition 4.1 we see an effect of green lobbying on the abatement of not only the lobby's host country but also other members. We refer to this as the leverage effect of green lobbying in member countries.

## 4.4 IEA Formation

To solve the participation stage of the game we apply the concept of potential internal stability (Carraro et al., 2006; Weikard, 2009) which employs the idea that transfers between coalition members can guarantee internal stability if and only if the coalition payoff (weakly) exceeds the sum of outside option payoffs. The outside option payoff is the payoff that accrues to a member when it leaves the coalition while the others maintain membership (as we only consider single deviations). Potential internal stability is a refinement of the concepts of internal and external stability that are widely used in IEA analysis. These concepts, initially borrowed from cartel-theory (d'Aspremont et al., 1983), define a stable coalition as one in which no member is better off by leaving the coalition and no non-member gains by joining the coalition. To ease the analysis and drawing on the fact that the subgame starting at stage 3, the abatement game with lobbying, has a unique equilibrium, we can define a partition function, that is, we can write each government's payoff as a function of the coalition that has been formed at the previous stage.

$$V_i(S) \equiv \pi_i^S(q_i^s, q), i \in S$$

$$V_i(S) \equiv \pi_i^{out}(q_i^{out}, q), i \in N \setminus S.$$

In a setting with symmetric countries an analysis of IEA stability is usually based on a stability function that describes the incentives of a country to be a member of a coalition as a function of the size of the coalition. In our setting with asymmetric countries incentives of a country to be in coalition $S$ may depend on the characteristics of the members of $S$. A country's incentive $\Gamma_i$ to participate in $S$ is defined as $\Gamma_i \equiv V_i(S) - V_i(S_{-i})$. Potential internal stability is defined as follows.

**Definition 4.1.** *Coalition $S \subseteq N$ is potentially internally stable if and only if $\sum_{i \in S} \Gamma_i \geq 0$.*

Given the specifications we have adopted, and using notation $q^*(S)$ for the equilibrium abatement at stage 3, we can write the condition of potential internal stability as follows.

$$\begin{aligned}\Gamma(S) \equiv \sum_{i \in S} \Gamma_i = \sum_{i \in S} bq^*(S) - \sum_{i \in S} \frac{1}{2} c(q_i^*(S))^2 + \sum_{i \in S} \lambda_i [L_i^f(q_i^*(S)) + L_i^g(q^*(S)))] \\ - \sum_{i \in S} bq^*(S_{-i}) + \sum_{i \in S} \frac{1}{2} c(q_i^{out})^2 - \sum_{i \in S} \lambda_i [L_i^f(q_i^{out}) + L_i^g(q^*(S_{-i}))]. \quad (4.10)\end{aligned}$$

Since in absence of lobbying countries are symmetric by assumption, we obtain in this case from equation (4.10)

$$\Gamma(S) = \sum_{i \in S} b[q^*(S) - q^*(S_{-i})] - \sum_{i \in S} \frac{1}{2} c[(q_i^*(S))^2 - (q_i^{out})^2]. \quad (4.11)$$

By substituting $q_i^*(S) = \frac{\sum_{j \in S} b}{c}$ and $q_i^{out} = \frac{b}{c}$ into (4.11) we obtain the well-known result that a coalition of three countries is internally stable (c.f. e.g. Barrett, 1994). We can now turn to the effects of lobbying activities on the stability of IEAs through further inspection of (4.10).

We can show the following.

**Proposition 4.2.** *Lobbying activities in free-riding countries have no effect on coalition stability.*

*Proof.* Appendix 4.6.2. □

Both green and firm lobbying activities in non-signatory countries have no effect on the coalition stability. This holds although lobbying in these countries changes their emissions abatement and in turn also the benefits of coalition members. The incentives to join or leave the coalition are unaffected by non-signatories' lobbying because the change of benefits through spillovers affects the coalition payoff and the outside option payoff in the same way.

**Proposition 4.3.** *(i) Contributions of a green lobby in a signatory country with (sufficiently) high political revenues from abatement have a positive effect on coalition stability. (ii) Contributions of a green lobby in a signatory country with (sufficiently) low political revenues from abatement have a negative effect on coalition stability.*

*Proof.* Appendix 4.6.3. □

To understand the intuition for Proposition 4.3 it is helpful to think about the different types of gains from cooperation that occur when a country joins the coalition in relation to its gains as a free-rider. On the one hand, welfare gains are achieved by internalizing the positive externalities among the members. However, these gains also benefit free-riding countries. Finus and McGinty (2015) argue that a second type of gains from joining a coalition exists and is of high importance for the stability of the coalition: the gains from cost-effective cooperation which are exclusive to the members and thus increase the gains from cooperation relative to the gains from free-riding[10]. Finus and McGinty (2015) show that those gains increase with the degree of asymmetry of benefit shares. For singletons, large asymmetries of marginal benefits will result in abatement choices characterized by large differences of marginal costs between countries. The latter implies an inefficiency, that can be removed when countries form a coalition. In our case we see that green lobby-contributions in a country with already existing strong lobbies increase coalition stability. This results from an increase of the asymmetry of marginal political revenues that member countries get from abatement, as this increases cooperative gains that are exclusive to the coalition. Conversely, additional green lobby contributions in a member country with low green lobby contributions decrease asymmetry of political revenues from abatement and thus have a negative effect on the gains from cooperation and coalition stability.

**Proposition 4.4.** *The effects of firms' lobbying activities in a signatory country on coalition stability depend on the distribution of green lobby activities across other member countries. Firms' lobby activities will have a positive effect on coalition stability if political revenues from abatement are evenly distributed. If political revenues of other member countries are sufficiently dispersed, firms' lobbying activities will have a negative impact on coalition stability.*

*Proof.* Appendix 4.6.4. □

This result can best be understood in light of the findings of Finus and McGinty (2015). They show that highly asymmetric benefits between members may help to stabilize large coalitions. Here we see that in these cases where strong green lobbying in just few countries (strong asymmetry of political revenues between member countries) stabilizes larger coalitions, firms' lobby contributions counteract the stabilization. Firms' lobby contributions can then effectively

[10]Note that these gains hinge on the existence of transfers as discussed by Weikard and Dellink (2014).

reduce the size of the IEA and, in turn, lower the abatement of both the remaining members and of countries leaving the coalition. In contrast, when green lobby contributions are similar in member countries (weak asymmetry of political revenues between member countries) then firms' contributions may increase coalition stability. This could generate larger coalitions, but with modest abatement targets of the member countries as firms' contributions drives political revenues.

## 4.5 Conclusions

In this chapter, we analyze the effects of political pressure groups (lobbies) on the emissions abatement decisions of countries and on the stability of IEAs. We study IEAs as a coalition formation process. The formation of an IEA is modeled as a game in which lobbies announce their contributions at the first stage before governments choose their participation. In the next stage countries choose their abatement strategies considering both net benefits of abatement and lobby contributions. Finally lobby contributions are paid contingent on the governments abatement decisions. We assume that there are two lobbies from which governments obtain contributions: industry and environmentalist. We consider that the levels of the respective contributions depend on each lobby's payoff function and the abatement strategy chosen by the government. The payoff of an environmentalist lobby depends on the additional abatement efforts undertaken by the government. Further we assume that the industry lobby is always harmed if the government increases abatement.

In our model, lobby contributions have an effect on the abatement decisions of IEA signatories and outsiders. Firms' contributions reduce emissions abatement of the host country of the lobby while environmentalists' contributions give incentives for more ambitious abatement targets. While firms' lobbying activities only influence the abatement levels of the host country, be it a coalition member or a free-rider, we observe a leverage effect of green lobbying activities in member countries: a stronger green lobby increases the abatement levels not only of the host country but also of all other members.

The effects on the coalition stability in contrast are ambiguous. Lobbying activities in free-riding countries have no effect on the stability of IEAs whereas lobby-groups in countries that are coalition members affect the coalition's stability. Firms' lobby-contributions have a stabilizing effect on the coalition if benefits from abatement are evenly distributed among members. If benefits from abatement are sufficiently dispersed among other members, firms' contributions will have a negative impact on coalition stability. The effect of green lobby contributions also depends on the distribution of benefits that governments gain from abatement: if the host country has sufficiently high revenues from abatement they have a positive effect on coalition stability. However, if the host country has sufficiently low revenues from abatement green lobby-contributions have a destabilizing effect. Our results qualify the findings of Marchiori et al. (2017) by allowing for asymmetric countries. In case of symmetric countries we also find a stabilizing effect of firm's lobby contributions on the coalition. However, this effect changes when countries are sufficiently asymmetric in their benefits from abatement in which case increasing firm contributions decrease coalition stability. We can conclude that the influence of lobby groups does not only change the abatement decisions of countries but also affects the stability of IEAs. It indeed may have a positive effect on the stability of IEAs but the effects on coalition stability crucially depends on the composition of the coalition and is often not straightforward. Further extensions of our work could include the analysis of transnational lobby activities. This can include industry lobby groups and green NGOs at an international scale as well as national lobby groups that have direct influence on other than their home countries.

## 4.6 Appendix

### 4.6.1 Proof of Proposition 4.1

As the abatement decisions are given by (4.8) for singletons and (4.9) for IEA-signatories, comparative statics show that (1) firms' lobby activities lower abatement:

$$\forall i \in N \setminus S : \frac{\partial q_i^{out}}{\partial \phi_i} = -\frac{\lambda_i(b + \lambda_i \gamma_i)}{c(1 + \lambda_i \phi_i)^2} < 0,$$

$$\forall i \in S : \frac{\partial q_i^{s}}{\partial \phi_i} = -\frac{\lambda_i \sum_{i \in S} (b + \lambda_i \gamma_i)}{c(1 + \lambda_i \phi_i)^2} < 0.$$

(2) Greens' lobby activities increase abatement:

$$\forall i \in N \setminus S : \frac{\partial q_i^{out}}{\partial \gamma_i} = \frac{\lambda_i}{c(1 + \lambda_i \phi_i)} > 0$$

$$\forall i \in S : \frac{\partial q_i^{s}}{\partial \gamma_i} = \frac{\lambda_i}{c(1 + \lambda_i \phi_i)} > 0$$

(3) Green lobby activities of signatories have positive spillover effects on other members

$$\forall i, j \in S, j \neq i : \frac{\partial q_i^s}{\partial \gamma_j} = \frac{\lambda_j}{c(1+\lambda_i \phi_i)} > 0.$$

It is also clear that singletons are not affected by any spillovers

$$\forall j \neq i : \frac{\partial q_i^{out}}{\partial \phi_j} = 0,$$

$$\forall j \neq i : \frac{\partial q_i^{out}}{\partial \gamma_j} = 0,$$

and that firms' lobbying in country $i \in S$ does not affect other members

$$\forall i, j \in S, j \neq i : \frac{\partial q_i^s}{\partial \phi_j} = 0.$$

□

### 4.6.2 Proof of Proposition 4.2

Substituting the specifications of lobby contributions in eqs. (4.3) and (4.4) into equation (4.2) we obtain $\pi_i = bq - \frac{1}{2}cq_i^2 + \lambda_i \gamma_i q + \lambda_i(\widehat{L}_i^f - \phi_i \frac{1}{2} c q_i^2)$. Rearranging gives $\pi_i = (b + \lambda_i \gamma_i)q - \frac{1}{2}c(1 + \lambda_i \phi_i)q_i^2 + \lambda_i \widehat{L}_i^f$. Now define $\beta_i \equiv b + \lambda_i \gamma_i$ and $\alpha_i \equiv c(1 + \lambda_i \phi_i)$ in order to write

$$\pi_i = \beta_i q - \frac{1}{2}\alpha_i q_i^2 + \lambda_i \widehat{L}_i^f. \tag{4.12}$$

This shows that our game with lobbying can be represented as a linear quadratic goods game with asymmetric players. Using (4.12) and the optimal abatement levels (4.8) and (4.9) we can rewrite eq. (4.10), the condition for potential internal stability as follows[11]:

$$\Gamma = -\frac{1}{2}\left(\sum_{i \in S}\beta_i\right)^2 \sum_{i \in S}\frac{1}{\alpha_i} - \frac{3}{2}\sum_{i \in S}\frac{\beta_i^2}{\alpha_i} + \sum_{i \in S}\beta_i \sum_{i \in S}\frac{\beta_i}{\alpha_i} + \sum_{i \in S}\beta_i^2 \sum_{i \in S}\frac{1}{\alpha_i}. \tag{4.13}$$

[11]Condition (4.13) has also been established by Weikard (2009, eq. 10).

It is clear from (4.13) that coalition stability only depends on parameters $\alpha_i$ and $\beta_i$ with $i \in S$ and, thus, is independent of lobby activities of non-signatories. □

### 4.6.3 Proof of Proposition 4.3

We examine the effect of green lobby activities in a member country on coalition stability by checking the sign of $\frac{\partial \Gamma}{\partial \gamma_i}$. Notice that $\frac{\partial \beta_i}{\partial \gamma_i} = \lambda_i$ and $\frac{\partial \alpha_i}{\partial \gamma_i} = 0$. Hence we can simply consider $\frac{\partial \Gamma}{\partial \beta_i}$. Taking derivatives of (4.13) we obtain

$$\frac{\partial \Gamma}{\partial \beta_i} = \sum_{j \in S} \frac{1}{\alpha_j} \left( 2\beta_i - \sum_{j \in S} \beta_j \right) + \sum_{j \in S} \frac{\beta_j}{\alpha_j} + \frac{1}{\alpha_i} \sum_{j \in S} \beta_j - 3\frac{\beta_i}{\alpha_i}$$

$$= \left( \frac{1}{\alpha_i} + \sum_{j \in S_{-i}} \frac{1}{\alpha_j} \right) \left( \beta_i - \sum_{j \in S_{-i}} \beta_j \right) + \sum_{j \in S_{-i}} \frac{\beta_j}{\alpha_j} + \frac{1}{\alpha_i} \sum_{j \in S_{-i}} \beta_j - \frac{\beta_i}{\alpha_i}$$

$$= \beta_i \sum_{j \in S_{-i}} \frac{1}{\alpha_j} - \sum_{j \in S_{-i}} \frac{1}{\alpha_j} \sum_{j \in S_{-i}} \beta_j + \sum_{j \in S_{-i}} \frac{\beta_j}{\alpha_j}$$

$$= \sum_{j \in S_{-i}} \frac{1}{\alpha_j} \left( \beta_i - \sum_{j \in S_{-i}} \beta_j \right) + \sum_{j \in S_{-i}} \frac{\beta_j}{\alpha_j}.$$

We can see from the first term that it has a positive sign if $\beta_i$ is sufficiently large. This is the case if $\gamma_i$ is sufficiently large, given the strengths of the lobby contributions in all other signatory countries. □

### 4.6.4 Proof of Proposition 4.4

We examine the effect of firms' lobby activities in a member country on coalition stability by checking the sign of $\frac{\partial \Gamma}{\partial \phi_i}$. Notice that $\frac{\partial \Gamma}{\partial \phi_i} = \frac{\partial \Gamma}{\partial \alpha_i} \frac{\partial \alpha_i}{\partial \phi_i}, \frac{\partial \alpha_i}{\partial \phi_i} = c\lambda_i > 0$ and $\frac{\partial \beta_i}{\partial \phi_i} = 0$ . Hence we can simply consider $\frac{\partial \Gamma}{\partial \alpha_i}$. Taking derivatives of (4.13) we obtain

$$\begin{aligned}
\frac{\partial \Gamma}{\partial \alpha_i} &= -\frac{1}{\alpha_i^2}\left(-\frac{1}{2}\left(\sum_{j\in S}\beta_j\right)^2 + \sum_{j\in S}\beta_j^2 + \beta_i\sum_{j\in S}\beta_j - \frac{3}{2}\beta_i^2\right) \\
&= -\frac{1}{\alpha_i^2}\left(-\frac{1}{2}\left(\beta_i + \sum_{j\in S_{-i}}\beta_j\right)^2 + \beta_i^2 + \sum_{j\in S_{-i}}\beta_j^2 + \beta_i^2 + \beta_i\sum_{j\in S_{-i}}\beta_j - \frac{3}{2}\beta_i^2\right) \\
&= -\frac{1}{\alpha_i^2}\left(-\frac{1}{2}\beta_i^2 - \beta_i\sum_{j\in S_{-i}}\beta_j - \frac{1}{2}\left(\sum_{j\in S_{-i}}\beta_j\right)^2 + \sum_{j\in S_{-i}}\beta_j^2 + \beta_i^2 + \beta_i\sum_{j\in S_{-i}}\beta_j - \frac{1}{2}\beta_i^2\right) \\
&= -\frac{1}{\alpha_i^2}\left(\sum_{j\in S_{-i}}\beta_j^2 - \frac{1}{2}\left(\sum_{j\in S_{-i}}\beta_j\right)^2\right).
\end{aligned}$$

The term in brackets is negative for an even distribution of other member countries' green lobby activities. Hence $\frac{\partial \Gamma}{\partial \phi_i} > 0$ and the impact of firms' lobby contribution on coalition stability is positive. As green lobby activities in other member countries are sufficiently dispersed, the term brackets will be positive and, hence, $\frac{\partial \Gamma}{\partial \phi_i} < 0$. Then the impact of firms' lobby contribution on coalition stability is negative. □

# 5 | Boon or Bane? Trade Sanctions and the Stability of IEAs

## 5.1 Introduction

In spite of scientific agreement on the negative effects of anthropogenic climate change, efforts to find cooperative solutions at the international UN climate negotiations have been unsatisfactory so far.[12] Game theoretic strands of economic literature have studied the formation and stability of international environmental agreements and found that it is difficult to reach large stable climate coalitions due to strong free-rider incentives (see Marrouch and Ray Chaudhuri, 2016, for a comprehensive overview of the literature).[13]

Given the global public bad characteristics of greenhouse gas emissions, the absence of global cooperation gives rise to two important questions for countries intending to enhance global emission abatement: (i) How to design second-best unilateral policies and (ii) how to incentivize broader cooperation? A principal approach to both questions is to link climate and trade policy: the use or the threat of trade measures against countries without emission regulations.

As to (i), the policy debate is concerned with drawbacks of unilateral policies associated to carbon leakage, i.e. an emission increase in unconstrained regions triggered by domestic climate policy. Two interrelated mechanisms can lead to carbon leakage (Felder and Rutherford, 1993): a shift of emission-intensive production to competitors abroad due to cost-disadvantages from carbon pricing for domestic firms. Likewise, international prices for fossil fuels might drop due to climate policies, thereby incentivizing higher fossil fuel consumption in unregulated economies. Anti-leakage measures are discussed, among others, in the form of border carbon adjustments: countries with a domestic carbon price could tax carbon embodied in imports from unregulated regions, and likewise rebate carbon payments to exports to unregulated regions.[14]

[12] This chapter is based on Hagen and Schneider (2017).

[13] Recent extensions of the game theoretic literature include inter alia multiple agreements (Chapter 3) or minimum participation constraints (Weikard et al., 2015; Carraro et al., 2009).

[14] In policy proposals, border carbon adjustments are primarily considered for sectors that show high emission and trade intensities.

A major finding of applied studies on border carbon adjustments is that they shift substantial parts of the burden of emission reduction to developing countries. The burden shifting effect is related to the economic theory on optimal tariffs (Limão, 2008): countries are able to benefit from the introduction of import tariffs in terms of domestic welfare, while their trading partners suffer losses. The basic mechanism is a change in the ratio of export and import prices – the terms of trade – in favor of the tariff imposing country.

The rationale for trade sanctions to approach question (ii) builds on the aforementioned insight from trade theory that import tariffs can benefit the importer and hurt the exporting country, as this could make import tariffs a credible threat in the international game for greenhouse gas reductions. Tariffs in this case are imposed as sanctions and are meant to be punitive to non-participants.[15] The rationale for the use of trade sanctions is thus rather rooted in strategic considerations: cooperation on free trade is made conditional on cooperation on emission abatement.

To date, there are no trade measures in climate policy in place.[16] Nonetheless, trade measures in the form of border carbon adjustments are mentioned as possible complementary measures in the EU Emissions Trading Directive (2009/29/EC) as well as in all the major US climate bills, i.e. the Waxman-Markey bill (US Congress, 2009), the Kerry-Boxer bill (Larsen et al., 2009), and the Cantwell-Collins bill (Larsen and Bradbury, 2010). The justification of trade measures in these climate policy legislations and bills has focused on carbon leakage and related concerns on competitiveness losses of emission-intensive and trade-exposed domestic industries.

In recent years, the focus of the debate on trade measures has shifted from tariffs as a second-best instrument combating carbon leakage to the appeal of tariffs as a strategic stick to foster cooperation. In particular, the announced withdrawal of the US from the Paris Agreement has opened a new debate on the role of punitive tariffs (Kemp, 2017).[17]

Previous studies on trade sanctions as a strategic means in climate policy have concluded that even low import tariffs are an effective tool to reach larger coalitions (Lessmann et al., 2009; Nordhaus, 2015). However, these studies rely on the assumption that outsiders of the coalition are not able to retaliate by imposing import tariffs themselves.[18] This is a crucial assumption

[15] Prominently, Joseph Stiglitz has explicitly argued in this vein, stating "Fortunately, we have an international trade framework that can be used to force states that inflict harm on others to behave in a better fashion." (Stiglitz, 2006)

[16] In contrast, in the Montreal Protocol from 1987, which controls substances that deplete the ozon layer, the incorporation of trade measures is considered to have been successful as a threat to ensure full cooperation (Barrett, 2011).

[17] Former French President and then presidential candidate Nicolas Sarkozy: "And so I ask that Europe construct a carbon tax at Europe's borders, a tax of one to three percent for all the products that come from the United States, if the United States exempts itself from the environmental regulations that we ourselves have imposed on our businesses." (Harvey, 2016).

[18] An exception is Böhringer et al. (2016), who include retaliation but don't use a concept of internal coalition

given that China has already threatened with trade war should it be subjected to border carbon adjustments (Voituriez and Wang, 2011) and given increased concerns over protectionism and trade war (Denyer, 2017).

In this paper, we take a more comprehensive approach and compare implications for coalition stability under three principal policy regimes: (i) A regime without trade sanctions; (ii) a regime in which coalition members use trade sanctions in the form of import tariffs against outsiders; and (iii) a regime in which coalition members use trade sanctions and outsiders retaliate with import tariffs.

We combine stylized theoretical analysis in a non-cooperative game theoretic model and numerical analysis in a static multi-region, multi-sector CGE model of global trade and energy use. Our theoretical findings suggest that trade sanctions increase the incentives to cooperate when retaliation is prohibited, which is in line with former findings in the literature. Considering retaliation by outsiders, however, leads to a "threshold"-effect: coalitions above a certain size are stabilized compared to the regime without trade sanctions, while coalitions below this threshold are destabilized. This leads to multiple equilibria. In particular, non-cooperation (the empty coalition) is always stable in the regime with retaliation. Our numerical analysis indicates that prospects for cooperation are reduced substantially when outsiders are able to retaliate; the size of the smallest internally stable coalition (other than the empty coalition) in scenarios with trade sanctions and retaliation is well above the size of the stable coalition in the absence of trade sanctions for most scenarios.

Our contribution to the existing literature is twofold. First, former analyses of trade sanctions as a means to foster cooperation in climate policy largely relies on the assumption that outsiders are not able to respond to trade sanctions with retaliation. We consider a regime in which outsiders do retaliate in a theoretical model of an international environmental agreement. Second, we use a multi-sector, multi-region CGE model with a full representation of international trade. This allows a quantification of our analytical findings in a setting with asymmetric regions and where regional and global welfare effects due to climate and trade policies are fully endogenized.[19] This is of particular virtue as the basic mechanism affecting incentives for cooperation is welfare changes through trade policy.

The remainder of the chapter is structured as follows: In Section 5.2, we review related theoretical and applied literature. In Section 5.3, we briefly discuss the economic rationale for the use of trade sanctions. After that, we lay out the assumptions in our three policy regimes in detail. In Section 5.4, we formulate the theoretical model. We subsequently present results on coalition stability under the three regimes. Section 5.5 introduces the CGE model and data.

stability.

[19]Nordhaus (2015) argues that including a full international trade model is unnecessarily complex. Instead he uses what he calls "reduced-form tariff benefit functions" to represent regional welfare changes induced by tariffs in his C-DICE model. These functions are calibrated using a trade model by Ossa (2014).

The quantitative results are discussed in Section 5.6 before we conclude in Section 5.7.

## 5.2 Literature Review

This chapter relates both to the game theoretic literature on the nexus of coalition stability and trade and to the applied literature on trade measures in subglobal climate policies. We give an overview of these strands of literature where we focus on work that is more closely related to our considerations.

The game theoretic literature on IEAs started to analyze the logic of coalition formation in the 1990s with seminal papers by Hoel (1992b), Carraro and Siniscalco (1993), and Barrett (1994). Barrett (1997a) shows in a model with symmetric countries that a trade ban accompanied by a minimum participation clause may help to sustain full cooperation on the provision of a global public good. In contrast, Dong and Zhao (2009) allow for endogenous tariffs which do not serve as a sanction to enforce higher cooperation in their model of an IEA. They find that the total effect of trade on IEA-participation can be positive or negative so that it is not clear if trade increases cooperation. Conconi and Perroni (2002) show in a cooperative game theoretical setting with three symmetric countries that linking decisions on trade and environment can have positive effects on cooperation if environmental costs and benefits are small compared to the costs and benefits of trade policies but can rather hinder cooperation for broader issues like climate change. Neumayer (2002) and Egger et al. (2011) empirically study determinants of cooperation in environmental agreements and find that trade openness has a positive influence on participation. Eichner and Pethig (2013) analyze IEA-formation in a model with consumption and production of fossil fuel and a composite consumer good and international trade. They find that with free trade larger coalitions may be sustained than under autarky, but achieve only slight emissions reductions. The model is extended in Eichner and Pethig (2014) where they show that the additional option of a fossil-fuel supply tax may increase global emissions reductions.

The applied literature has thoroughly studied border carbon adjustments as a measure to overcome drawbacks of unilateral carbon pricing associated with carbon leakage – for overview articles see Böhringer et al. (2012) and Branger and Quirion (2014). The focus of this literature has been on the ability of border measures as a means to combat carbon leakage, improve the global cost effectiveness of emission abatement, and reduce adverse impacts on domestic emission-intensive and trade-exposed industries being subjected to unilateral emission regulation. The main findings on border carbon adjustments are that they markedly reduce carbon leakage but their impact on global costs is only moderate. Their main effect is a strong burden shifting from abating to unregulated regions through changes in relative prices of traded goods (terms of trade).

Recently, the focus in applied research has shifted towards the idea of using trade measures not as means to improve sub-global policies given a certain climate coalition, but as a stick to incentivize cooperation and to enlarge the coalition. To our best knowledge, only two papers explicitly take into account possible retaliation by regions subjected to tariffs. Böhringer et al. (2016) use a static computable general equilibrium (CGE) model and set up a game between a coalition that is going forward with carbon pricing and non-coalition regions. The coalition can use carbon tariffs against outsiders. Non-coalition regions can either join the coalition, retaliate, or do nothing. They show that – even under the threat of retaliation – trade measures can spur prospects for cooperation. However, they do not use a concept of internal stability of the climate coalition. Böhringer and Rutherford (2017) investigate prospects of trade sanctions against the US in order to coerce the US back into the Paris Agreement. They find that even trade war is no credible threat against the US, as the market power of the US on international markets is too large.

Most closely related to our analysis are the studies by Lessmann et al. (2009) and Nordhaus (2015). Lessmann et al. (2009) develop a dynamic model of cooperation and study the effect of trade sanctions in the form of import tariffs on participation in an IEA. They find that low tariff rates of 1.5 to 4% are sufficient to induce full cooperation. By assumption, however, outsiders are not able to retaliate.

In a more recent study, Nordhaus (2015) also suggests trade sanctions in his proposal for a mechanism that may help to stabilize an international environmental agreement that he calls 'climate club'.[20] These sanctions – in the form of uniform import tariffs – are put in place against outsiders to increase cooperation and stabilize the climate agreement. From numerical simulations he concludes that prospects for international cooperation increase substantially when abating regions impose small trade sanctions against non-participants. As in Lessmann et al. (2009), his results rely on the assumption that outsiders are not able to respond to trade sanctions by members, assuming the treaty would prohibit retaliation.

## 5.3 Trade Sanctions, Policy Regimes, and Stability

In order to lay out policy regimes we need to be clear about the economic rationale behind import tariffs as a sanctioning mechanism, which traces back to Bickerdike (1906). We discuss this in a non-technical way and describe the details of the policy regimes we analyze in subsequent sections. This forms the basis for our analytical and numerical considerations.

Assume a large importing region in an undistorted equilibrium. In theory, the domestic welfare effect of imposing import tariffs is driven by two opposing factors: (i) The tariff reduces demand for the imported good, which puts a downward pressure on the respective import price.

[20]Note that there exist other definitions of the concept of climate clubs – see e.g. Weischer et al. (2012), Widerberg and Stenson (2013), and Chapter 3.

Consequently, the ratio of export and import prices changes in favor of the tariff imposing country, which can now pay for more physical units of imports with the same physical amount of exports. This is the terms-of-trade effect. In that sense, the tariff works as a substitute for the exertion of market power by consumers on the demand side. (ii) Starting from an undistorted equilibrium, the tariff creates a deadweight loss.

In a linear demand and supply structure, domestic welfare improvements due to the first effect are proportional to the tariff rate, while the deadweight loss is quadratic in the tariff rate. This implies that for low tariff rates the former effect dominates the latter, i.e. there is scope for welfare improvements for tariff rates up to an "optimal tariff" for the taxing country. Global welfare, however, will unambiguously decline compared to the undistorted equilibrium due to the deadweight loss.

We represent these effects in a very stylized way in our analytical model. In the CGE framework, price changes – and thus terms-of-trade effects – as well as costs due to trade distortions are endogenous to the represented production, consumption, and trade activities.

We investigate three different policy regimes for international climate policy analytically and numerically. In all regimes, we assume a global social cost of carbon (SCC) as an exogenous parameter. The global SCC translates into regional SCCs via GDP-shares which can be interpreted as a regional constant marginal benefit of emission abatement. In a non-cooperative setting each region has an incentive to abate emissions up the point where marginal abatement cost equal marginal benefits, i.e. to introduce a $CO_2$ tax equal to its regional SCC. We refer to this reference situation as the empty coalition.

In our first policy regime – denoted *NTRF* – we allow cooperation but no trade sanctions. In this case, regions can form coalitions in order to jointly maximize their net payoffs. In the second regime – denoted *UTRF* – coalition members unilaterally impose trade sanctions on outsiders in the form of uniform import tariffs. Outsiders are prohibited from retaliating. Under the third regime – denoted *RTRF* – coalition members impose trade sanctions and outsiders retaliate by imposing uniform import tariffs themselves.

To investigate coalition stability under different regimes, we apply the concepts of internal and external stability (d'Aspremont et al., 1983) which are standard in the literature of IEAs (Hoel, 1992b; Carraro and Siniscalco, 1993; Marchiori et al., 2017). Internal stability implies that no member country has an incentive to leave the agreement whereas the external stability condition is satisfied if no outsider has an incentive to join the existing coalition.

## 5.4 Analytical Model

To study the qualitative effects of trade sanctions and retaliation on the stability of IEAs we setup a stylized non-cooperative game theoretical model which follows standard assumptions in the IEA-literature (Marrouch and Ray Chaudhuri, 2016; Finus, 2001, Chapter 2) before the simulations in the calibrated CGE model allow for a quantification of the impacts. The policy regimes without trade sanctions (*NTRF*) and with unilateral trade sanctions (*UTRF*) are completely in line with former work. We develop them here for the sake of completeness and in order to set up definitions and function specifications to arrive at our main result on coalition stability under trade sanctions and retaliation ( *RTRF*). We analyze stable coalitions in the *NTRF* regime and then study the impact of a policy regime shift to *UTRF* and *RTRF* on the stability of coalitions.

### 5.4.1 The Two-Stage Game

The model is set up as a two-stage game (e.g. Barrett, 2001). At the first stage, countries decide if they join the climate coalition or not. At the second stage, the members of the coalition decide cooperatively about the amount of emission abatement in a simultaneous game between the coalition and the outsiders. Assume there are $N$ symmetric regions with individual payoffs from emission abatement given as

$$\Pi(q_i, Q) = bQ - C(q_i), \tag{5.1}$$

where $q_i$ is the amount of abatement undertaken by region $i = 1, \ldots, N$, and $Q = \sum_i q_i$ is the global amount of abatement. Parameter $b \geq 0$ denotes the constant marginal benefit of emission abatement for an individual region. Hence, we can interpret $b$ as the regional social cost of carbon, and $bN$ as the global social cost of carbon, accordingly. The abatement cost function $C$ is a thrice differentiable, monotonically increasing convex function with $C(0) = 0$, $C' > 0$, $C'' > 0$, and $C''' \geq 0$. We assume that trade sanctions don't affect abatement costs, thus results on optimal abatement for individual outsiders and coalition members are valid for all of our three policy regimes.

The model is solved by backward induction, solving the abatement stage first. At this stage of the game the number of coalition members $k$ is taken as given and thus not considered as a decision variable. In the following, we use $out$ as an index for outsiders and $coa$ as an index for coalition members. First, we determine the outsiders' abatement decisions $q^*_{out}$. Each outsider country chooses $q_{out}$ to maximize (5.1), so that

$$q^*_{out} = C^{'-1}(b). \tag{5.2}$$

It follows that the abatement decision of outsider countries is a dominant strategy and does not depend on other countries' decisions.[21] To determine the member countries' abatement decision

[21]Note that the dominant strategies of outsiders imply that the model results also hold for a sequential Stackelberg version of the game (as in e.g. Barrett, 1994; Diamantoudi and Sartzetakis, 2006; Rubio and Ulph, 2006) with

$q^*_{coa}$ we consider the joint payoff for a coalition with $k$ members, which is given by

$$k\Pi(q_{coa}, Q) = kbQ - kC(q_{coa}). \tag{5.3}$$

Maximization of (5.3) determines the amount of abatement $q^*_{coa}$ that is undertaken by any member country of the agreement as

$$q^*_{coa} = C'^{-1}(kb). \tag{5.4}$$

Comparing (5.2) and (5.4) shows that members of the coalition abate more emissions than outsiders do. A member country's emissions abatement depends on the size of the coalition but is independent of the outsiders' abatement decisions. Effectively, each member abates up to the point where marginal abatement cost equal joint marginal benefits in the coalition.[22]

Now we turn to the membership stage. Let $\Pi_{coa}(k)$ denote the payoff of an individual member in a coalition of $k$ and $\Pi_{out}(k)$ the payoff for an outsider. Formally, the stability conditions for a coalition of $k$ then read

$$\Pi_{coa}(k) \geq \Pi_{out}(k-1) \text{ for internal stability, and}$$
$$\Pi_{out}(k) > \Pi_{coa}(k+1) \text{ for external stability.}$$

Following Hoel and Schneider (1997) we define the stability function $\Phi$ in general as

$$\Phi(k) := \Pi_{coa}(k) - \Pi_{out}(k-1). \tag{5.5}$$

Thus, a coalition of size $k$ is internally and externally stable if $\Phi(k) \geq 0$ and $\Phi(k+1) < 0$. In the following, we use superscripts to distinguish between the three policy regimes *NTRF*, *UTRF*, and *RTRF*.

### 5.4.2 Policy Regime *NTRF*: Agreement Stability Without Trade Sanctions

We can use the the abatement decisions of coalition members (5.4) and outsiders (5.2) in the stability function for the regime without trade sanctions

$$\Phi^{NTRF}(k) = \Pi^{NTRF}_{coa}(k) - \Pi^{NTRF}_{out}(k-1) \tag{5.6}$$

and state the following Lemma, which assures the existence of a unique internally and externally stable coalition of at least 2 countries under $NTRF$.

---

the coalition deciding first and the outsiders behaving as Stackelberg-followers.

[22]We mirror this in our numerical analysis, where coalition members set a carbon tax equal to the sum of regional SCCs in the coalition, see Section 5.5.

**Lemma 5.1.** *1. The stability function $\Phi^{NTRF}(k)$ is monotonically decreasing in $k$ for all coalition sizes $k \geq 1$.*

*2. Coalitions of two countries are internally stable.*

*Proof.* Appendix 5.8.1. □

It follows that an internally and externally stable coalition is characterized by the largest integer $k$ that satisfies $\Phi^{NTRF}(k) \geq 0$. In case of a linear-quadratic specification of the payoff-function the size of an internally and externally stable coalition under $NTRF$ is $3$. Note that this result hinges on the assumption of linear benefits of abatement (as in e.g. Fuentes-Albero and Rubio, 2010; Pavlova and de Zeeuw, 2013). Other specifications of the model, as in Barrett (1994), find the possibility for large coalitions if benefits from cooperation are small. This effect is known as the paradox of cooperation. As we focus our analytical model on the effects of trade sanctions on the stability of IEAs we employ a linear-convex specification instead of emphasizing a more complex payoff structure.

### 5.4.3 Policy Regime *UTRF*: Trade Sanctions as a Means for Stability

Now assume that members of the coalition impose unilateral trade sanctions in the form of import tariffs at rate $\theta \geq 0$ on the outsiders. We assume throughout this section that the imposed tariff rate is below the optimal tariff rate. In line with our considerations from Section 5.3, each member will enjoy a welfare gain $\beta(\theta, N-k) \geq 0$ from the tariff while outsiders face a cost $\zeta(\theta, k) \geq 0$ and $\beta$ and $\zeta$ are monotonically increasing in $\theta$ (up to the optimal tariff rate). The magnitude of gains and costs for a specific tariff rate depend on the coalition size. We can assume that for an individual coalition member, the welfare gain will be greater in smaller coalitions, as more import flows are taxed at the border. Likewise, losses for outsiders will increase in the coalition size.

Thus, the stability function becomes[23]

$$\Phi^{UTRF}(k,\theta) = \Pi^{NTRF}_{coa}(k) + \beta(\theta, N-k) - \Pi^{NTRF}_{out}(k-1) + \zeta(\theta, k-1). \tag{5.7}$$

What can we say about moving from *NTRF* to *UTRF*, i.e. what is the effect of an imposition of unilateral trade sanctions on coalition stability? For a clear-cut comparison between *NTRF* and *UTRF*, we take a look at the net stability function, which we define as:

$$\Delta\Phi^{UN}(\theta,k) := \Phi^{UTRF}(\theta,k) - \Phi^{NTRF}(k) = \beta(\theta, N-k) + \zeta(\theta, k-1). \tag{5.8}$$

We can interpret the net stability function as the change in the basic incentive structure when moving from one regime to the other at a specific coalition size: positive values of the net

[23] Recall the assumption that trade sanctions don't affect abatement costs.

stability function $\Delta\Phi^{UN}$ indicate that under the $UTRF$ regime it is more attractive to be a member of a coalition of size $k$ than under $NTRF$, thus the coalition would be stabilized through the regime shift; likewise, negative values indicate that the respective coalition would be destabilized. The net stability function $\Delta\Phi^{UN}$ is unambiguously positive, which indicates that for every coalition size $k$ the incentive to be member of the coalition is higher under *UTRF* than under *NTRF* for any tariff rate $\theta$.[24]

### 5.4.4 Policy Regime *RTRF*: Agreement Stability with Trade Sanctions and Retaliation

The picture changes if outsiders react with retaliatory policies (regime *RTRF*). Assume that outsiders raise retaliatory trade sanctions at the same rate as the sanctioning tariff $\theta$. These in turn benefit the outsiders who gain $\beta(\theta, k)$. The members of the coalition who are now targeted by trade sanctions themselves lose $\zeta(\theta, N-k)$. The loss for coalition members thus increases with the level of retaliatory trade sanctions as well as with the number of outsiders that apply those sanctions. Including trade sanctions and retaliation, the stability function becomes

$$\begin{aligned}\Phi^{RTRF}(k,\theta) = \Pi_{coa}^{NTRF}(k) + \beta(\theta, N-k) - \zeta(\theta, N-k) \\ - \Pi_{out}^{NTRF}(k-1) + \zeta(\theta, k-1) - \beta(\theta, k-1).\end{aligned} \tag{5.9}$$

It is apparent that retaliation has a destabilizing effect compared to unilateral trade sanctions only (*UTRF*), as the net stability function

$$\Delta\Phi^{RU} = \Phi^{RTRF} - \Phi^{UTRF} = -\beta(\theta, k-1) - \zeta(\theta, N-k) \tag{5.10}$$

is unambiguously negative. The effect is the largest for small coalitions and decreases with the coalition size.

The more relevant question is: What can we say about a change from *NTRF* to *RTRF*? For simplicity, we make the further assumption that a tariff-imposing region receives the same benefit $\beta(\theta)$ from each region it taxes, i.e. $\beta(\theta, N-k) = (N-k)\beta(\theta)$. A similar assumption about the loss of targeted countries implies $\zeta(\theta, k) = k\zeta(\theta)$. With these additional assumption, we can formulate our key analytical finding.

**Proposition 5.1.** *The effect of trade sanctions and retaliation on coalition stability compared to a no-tariff regime depends on the coalition size. Coalitions below a threshold size of* $\bar{k} = (N+1)/2$ *are destabilized. For coalitions larger than size* $\bar{k}$ *the stabilizing effect of trade sanctions dominates.*

[24] Recall that we are assuming tariffs rates below the optimal tariff, i.e. sufficiently low to imply welfare gains for the imposing region.

*Proof.* Appendix 5.8.2. □

The stylized analytical representation of an IEA shows the main effects of the introduction of trade sanctions and the possibility of retaliation by outsiders on the agreement stability compared to the no-tariff regime. Trade sanctions serve as a means to stabilize coalitions if retaliation is prohibited. The stabilizing effect increases with the coalition size. However, retaliation has a destabilizing effect which is decreasing in the coalition size. The total effect of both sanctions and retaliation depends on the coalition size: for larger coalitions, the stabilizing effect of trade sanctions dominates, while for small coalitions the destabilizing effect of retaliation dominates. These opposed effects are to be quantified in a numeric modeling approach. Using a CGE model allows us to endogenize abatement costs as well as welfare effects triggered by trade measures and to quantify and visualize the effects of trade sanctions and retaliation with asymmetric countries based on real-world data.

## 5.5 Numerical Model, Data, and Scenarios

### 5.5.1 Numerical Model

For our quantitative assessment, we use a standard static multi-region, multi-sector CGE model of global trade and energy that was developed for numerical analyses on border carbon adjustments in sub-global climate policies. The CGE framework is particularly well suited to analyze quantitative implications of trade measures on coalition stability, as global and regional welfare implications of emission abatement and trade policies are fully endogenized. In this section, we provide a brief non-technical summary of the model. A detailed description including an algebraic formulation can be found in Böhringer et al. (2015).

Primary factors of production comprise labor, capital, and fossil resources. Labor and capital are assumed to be mobile across sectors within each region but not internationally mobile. Fossil resources (gas, crude oil, and coal) are sector-specific capital in fossil fuel production. Factor markets are perfectly competitive.

Final consumption in each region is represented through a representative agent who receives income from primary factors and maximizes welfare subject to a budget constraint and constant-elasticity-of-substitution (CES) utility.

The production of goods other than fossil resources is represented through a standard nested CES function, where at the top level a composite of value added, energy and material intermediate inputs trades off with a transport composite of international transport services. In fossil resource production, the specific resource factor trades off with a Leontief composite of all other inputs at a constant elasticity of substitution. Output of each production sector is allocated either to the domestic market or the export market according to a constant-elasticity-of-transformation function.

Government and investment demand are fixed at real benchmark levels. Investment is paid by savings of the representative agent while taxes pay for the provision of public goods and services.

International trade is modeled following Armington's differentiated goods approach, where goods are distinguished by origin (Armington, 1969). The Armington composite for a traded good is a CES function of domestic production for that sector and an imported composite. The import composite, in turn, is a CES function of production from all other countries. A balance of payment constraint incorporates the base-year trade deficit or surplus for each region.

$CO_2$ emissions are linked in fixed proportions to the use of fossil fuels, with region- and sector-specific $CO_2$ coefficients. Restrictions to the use of $CO_2$ emissions in production and consumption are implemented through exogenous $CO_2$ taxes. $CO_2$ emission abatement then takes place by fuel switching or energy savings – either by fuel-non-fuel substitution or by a scale reduction of production and final demand activities.

### 5.5.2 Data

For the calibration of model parameters, we use the latest version of the database from the Global Trade Analysis Project (GTAP version 9) with base-year 2011 (Aguiar et al., 2016). The GTAP database provides multi-region, multi-sector input-output tables, international trade flows on the sectoral level, sector- and fuel specific $CO_2$ data, as well as substitution elasticities for production and trade for 140 regions and 57 sectors. We aggregate the database according to our research questions, as summarized in Table 5.1. On the regional level, we follow Nordhaus (2015) and aggregate to the 15 major economic world regions including the USA, Europe, Japan, Russia, and China. On the sectoral level, we represent the most important sectors when it comes to the combination of carbon and trade policy: we individually represent the primary and secondary energy goods coal, crude oil, natural gas, and electricity. Additionally, we include aggregated sectors for energy- and trade- intensive industries, transport industries, and all other goods, respectively.

We calibrate the model to base-year input-output data, i.e. we determine the parameters such that the economic flows represented in the data are consistent with the optimizing behavior of the economic agents. The responses of agents to price changes are determined by a set of exogenous elasticities taken from the econometric literature. Elasticities in international trade (Armington elasticities) and substitution possibilities in production (between primary factor inputs) are directly provided by the GTAP 9 database. In fossil fuel production, elasticities of substitution between the resource and all other inputs are calibrated to match exogenous estimates of fossil-fuel supply elasticities (Graham et al., 1999; Krichene, 2002; Ringlund et al., 2008).

**Table 5.1:** Model sectors and regions

| Sectors and commodities | Countries and regions |
|---|---|
| *Energy sectors* | United States of America |
| Coal | Europe |
| Crude oil | China |
| Natural gas | India |
| Refined oil products | Russia |
| Electricity | Japan |
| *Aggregated sectors* | Canada |
| EITE* | South Africa |
| Transport | Brasil |
| All other goods | Mideast and North Africa |
| | Eurasia |
| | Latin America |
| | Tropical Africa |
| | Middle-income Asia |
| | Rest of the World |

* EITE – energy-intensive and trade-exposed sectors: chemical products; non-metallic minerals; iron and steel industry; non-ferrous metals; paper, pulp, and print.

### 5.5.3 Scenarios

One particular scenario in our simulations is composed of assumptions along four dimensions: the global social cost of carbon (SCC), the climate coalition, the policy regime, and the tariff rate, as summarized in Table 5.2.

**Global Social Cost of Carbon**

We include four different assumptions about the global SCC – 12.5, 25, 50, and 100 USD per ton of $CO_2$.[25] These assumptions are in line with Nordhaus (2015) and with recent recommendations by the High-Level Commission on Carbon Prices chaired inter alia by Joseph Stiglitz and Lord Nicholas Stern (Carbon Pricing Leadership Coalition, 2017). We denote the assumptions with SCC-12.5, SCC-25, SCC-50, and SCC-100.

**Coalitions**

Our analysis comprises 15 regions, which implies 32767 possible coalitions. Each region has an assigned regional SCC, which is calculated as its base-year share of global GDP times the global SCC. In the same way as laid out in the analytical model in section 5.4, coalitions are specified as follows: within a coalition, individual members take the sum of their regional SCC's into account, while outsiders act solely according to their own regional SCC. Effectively, coalition members apply a tax on $CO_2$ emissions equal to the sum of regional SCC's of

[25] For a comprehensive overview of simulations and applications of the concept of the social cost of carbon, see Metcalf and Stock (2017).

members, and outsiders apply a $CO_2$ tax equal to their own regional SCC. In the non-cooperative solution (equivalently: empty coalition) each region applies a $CO_2$ tax equal to their regional SCC.

**Policy Regimes and Tariff Rates**

Our policy regimes in the numerical analysis exactly refer to those laid out in Section 5.3: In the first regime *NTRF*, there are no trade sanctions, i.e. regions are solely applying $CO_2$ taxes, where the tax level depends on whether or not they are part of the coalition. In the second regime *UTRF*, we introduce trade sanctions in the form of import tariffs imposed by the climate coalition against outsiders. The import tariffs apply uniformly over all sectors of the economy. We include ad-valorem tariff rates from 1% to 10%. This range is in line with the political discussion, Nordhaus' analysis and – as the presentation in the next section reveals – covers the spectrum of results conceivable from our analytical analysis.[26] The third regime *RTRF* comprises trade sanctions as in *UTRF* and additionally retaliation by outsiders. In the case of retaliation (*RTRF*), our convention is that outsiders retaliate by applying the same uniform import tariff rate on imports from members that members apply for their part.

**Table 5.2:** Overview of simulation scenarios

| Dimension | Description and specification |
|---|---|
| Global social cost of carbon | We include four different assumptions about the global social cost of carbon: SCC-12.5, SCC-25, SCC-50, SCC-100 |
| Coalition | We include all possible 32767 coalitions |
| Policy regime | We include three different regimes: *NTRF*, *UTRF*, *RTRF* |
| Tariff rate | Under policy regimes *UTRF* and *RTRF*, we include ad-valorem import tariff rates of 1% to 10% |

**Business-as-Usual**

The non-cooperative solution serves as our business-as-usual for the assessment of welfare changes in the different scenarios.[27] Obviously, we have a different business-as-usual for each assumption about the global SCC. Table 5.3 gives an overview of our business-as-usuals under the four different assumptions about the global SCC. The first column shows the GDP shares in our base-year data, which together with the global SCC define the regional SCC, and

[26] An interesting extension would be a setting in which regions apply the welfare maximizing – i.e. optimal – tariff rate as e.g. in (Böhringer and Rutherford, 2017). For our analysis, however, the simpler assumption of fixed tariff rates is more appropriate as it relates to the political discussion, the analytical part and to former analysis by Nordhaus (2015).

[27] We calculate welfare as Hicksian equivalent variation (HEV): the amount of USD that has to be added to the representatives agents' business-as-usual income such that she enjoys the same utility level as in the counterfactual. In our case – as real government demand and real investment demand are fixed – regional HEV is the sum of the change in real private consumption and the change in global emissions valued at the regional SCC.

thus the regional $CO_2$ taxes in the business-as-usual. Consequently, the regional $CO_2$ taxes add up to the exogenous global SCC (row "Total"). Additionally, we report the global average $CO_2$ price, which is the emission-weighted sum of regional $CO_2$ taxes. We see that in the non-cooperative solution, the global average $CO_2$ price is only slightly above one tenth of the assumed global SCC.

**Table 5.3:** Business-as-usual regional GDP shares and $CO_2$ taxes under different assumptions about the global social cost of carbon

| | GDP share | SCC-12.5 $CO_2$ tax | SCC-25 $CO_2$ tax | SCC-50 $CO_2$ tax | SCC-100 $CO_2$ tax |
|---|---|---|---|---|---|
| Europe | 26.4 | 3.30 | 6.60 | 13.21 | 26.41 |
| United States of America | 21.7 | 2.72 | 5.43 | 10.87 | 21.73 |
| China | 10.6 | 1.32 | 2.65 | 5.29 | 10.59 |
| Japan | 8.3 | 1.03 | 2.07 | 4.13 | 8.26 |
| Mideast and North Africa | 5.6 | 0.70 | 1.40 | 2.79 | 5.58 |
| Latin America | 4.8 | 0.61 | 1.21 | 2.42 | 4.85 |
| Middle-income Asia | 3.7 | 0.47 | 0.93 | 1.86 | 3.72 |
| Brasil | 3.5 | 0.43 | 0.87 | 1.73 | 3.47 |
| Eurasia | 3.3 | 0.42 | 0.83 | 1.66 | 3.32 |
| Russia | 2.7 | 0.33 | 0.67 | 1.33 | 2.67 |
| India | 2.6 | 0.33 | 0.66 | 1.32 | 2.63 |
| Canada | 2.5 | 0.31 | 0.62 | 1.24 | 2.49 |
| Rest of the World | 2.2 | 0.28 | 0.56 | 1.12 | 2.24 |
| Tropical Africa | 1.5 | 0.19 | 0.37 | 0.74 | 1.48 |
| South Africa | 0.6 | 0.07 | 0.14 | 0.28 | 0.57 |
| Total | 100 | 12.5 | 25 | 50 | 100 |
| Global average | | 1.48 | 2.95 | 5.86 | 11.60 |

Note.— GDP share is given in % of world GDP; $CO_2$ tax is given in USD per ton of $CO_2$; Global average – emission-weighted average of regional $CO_2$ taxes.

Under each assumption about the global SCC, the policy regime, and the tariff rate, we calculate regional welfare changes for each of the 15 regions under all possible 32767 coalitions. In the next step, we check each coalition for internal and external stability, i.e. we compare for each member region whether it would be better off by leaving the coalition and for each outsiders region whether it would be better off by joining the coalition.

## 5.6 Results

In this section, again we discuss the results of our numerical analysis and relate them to insights from the analytical model in Section 5.4. First we provide an insight to the basic incentive structure under the three considered policy regimes. In the next part, we analyze findings on stable coalitions, before we take a closer look at how the incentive structure changes when moving from *NTRF* to *RTRF*. Finally, we discuss implications for global welfare and emission levels in stable coalitions under the different policy regimes.

### 5.6.1 Basic Incentive Structures

Before we present quantitative results on stable coalitions under the three policy regimes *NTRF*, *UTRF*, and *RTRF* in detail, we present the basic incentive structure with regards to cooperation. Figure 5.1 shows indicators for these incentives for the four major model regions in terms of GDP – the United States (US), the European Union (EU), China (CHN), and Japan (JPN): the "Benefit of in" and the "Cost of out" at an assumed global social cost of carbon of 25 USD and a tariff rate of 2%. The "Benefit of in" is the welfare change of a region if it forms a coalition of 1. The "Cost of out" is the welfare change of a region if it leaves the grand coalition.[28]

In the absence of trade sanctions (regime *NTRF*), the "Benefit of in" is zero in all regions, as a coalition of 1 is technically identical to the non-cooperative equilibrium. The EU is the only region with a positive "Cost of out", indicating they would even prefer to stay in the grand coalition. While the US and Japan would slightly benefit from leaving the grand coalition (in the form of negative cost), China has by far the strongest incentive to leave the grand coalition. They would save almost 20 billion USD when going from the grand coalition to the coalition of 14 without China. The underlying reason is the Armington structure of the model. Due to the differentiation of goods by origin, regions are able to pass costs due to carbon pricing through to trading partners. In that respect, carbon pricing can to some extent be a substitute for optimal tariffs and change the terms of trade in favor of the taxing region. Obviously, substitution possibilities for European goods are rather limited, thus Europe even prefers to remain in the grand coalition and apply higher carbon prices.[29]

In case of unilateral tariffs by the coalition (regime *UTRF*), we clearly see the unambiguously positive effect on individual regions incentives. All regions would now prefer to form a coalition of 1, as they would enjoy welfare gains from taxing all there incoming imports. On the other hand, all regions would suffer dramatically under leaving the grand coalition and thus be subjected to tariffs by all 14 remaining coalition members.

Now we turn to the comparison between the unilateral tariff regime (*UTRF*) and the retaliation regime (*RTRF*), i.e., incentives that may be misrepresented when retaliation is precluded by assumption. Under *RTRF*, we find that the "Cost of out" is smaller compared to

[28] These indicators where introduced in Nordhaus (2015).

[29] The ability to pass through increased production costs might be exaggerated in the Armington structure compared to trade models relying on Melitz' formulation of firm heterogeneity, where average firm productivities adjust endogenously (Melitz, 2003). For structural sensitivity analyses on impacts of carbon pricing and trade policies under different trade formulations see Balistreri and Rutherford (2012); Balistreri and Markusen (2009).

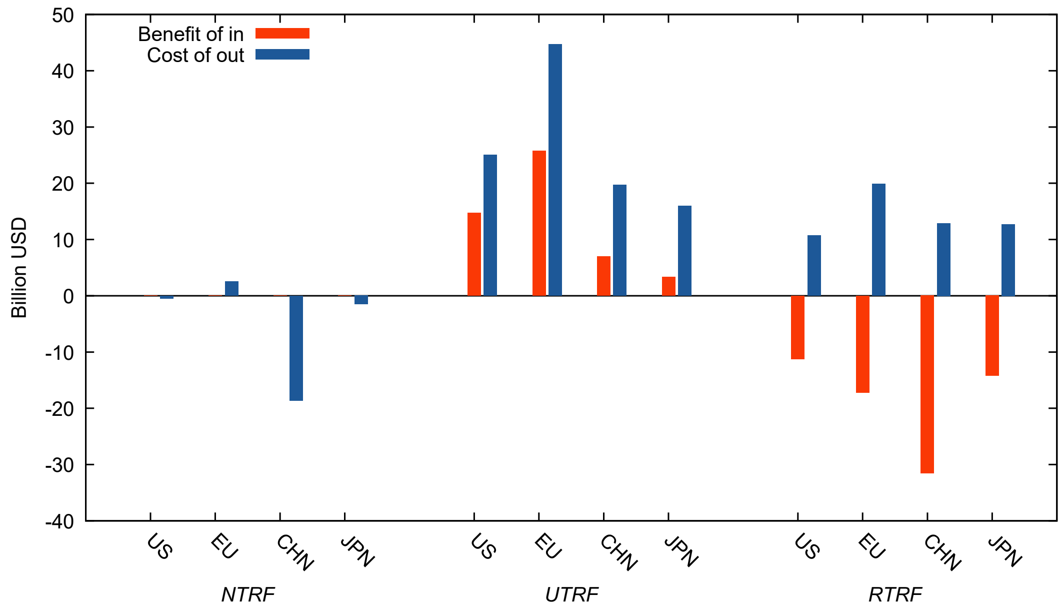


**Figure 5.1:** “Benefit of in” and “Cost of out” at a global social cost of carbon of 25 USD and a tariff rate of 2% under *NTRF*, *UTRF*, and *RTRF*. US – United States; EU – Europe; CHN – China; JPN – Japan; Benefit of in – welfare change of a region if it forms a coalition of 1; Cost of out – welfare change of a region if it leaves the grand coalition.

*UTRF*, yet still the represented regions clearly prefer to maintain the grand coalition. The incentive to starting coalitions, however, that was quite large under *UTRF*, has turned around and all the regions face substantial cost of between roughly 10 billion USD (US) and 30 billion USD (China) when forming a coalition of 1. In particular, this shows that the empty coalition is stable now.

This finding is exactly in line with our conclusion from the analytical part: Under a regime with unilateral trade sanctions, coalitions are stabilized unambiguously. But under a regime with trade sanctions and retaliation, larger coalitions tend to be stabilized, while smaller coalitions tend to be destabilized compared to regimes without trade sanctions.

### 5.6.2 Stable Coalitions

We now turn to stable coalition structures that result from the different policy regimes. Figure 5.2 shows the size of the stable coalitions in percentage share of world GDP in the policy regimes *NTRF*, *UTRF*, and *RTRF* for different assumptions about the global social cost of carbon and the different considered tariff rates from 1% up to 10% for the regimes *UTRF* and *RTRF*.

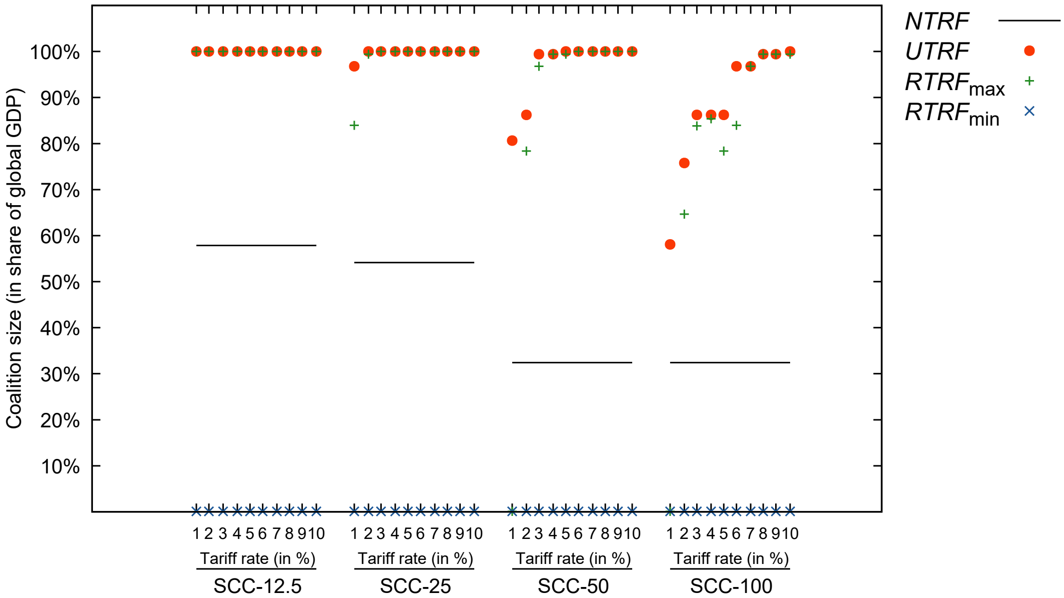


**Figure 5.2:** Percentage share of world GDP of stable coalitions in the policy regimes *NTRF*, *UTRF*, and *RTRF* for different assumptions about the global social cost of carbon $RTRF_{\text{max}}$ refers to the largest stable coalition under *RTRF*; $RTRF_{\text{min}}$ refers to the smallest stable coalition under *RTRF*.

### Policy Regime *NTRF*: Stable Coalitions in the Absence of Tariffs

In the absence of tariffs our simulations quantify the basic results from our analytical model in Section 5.4. In contrast to the expository simple analytical model with symmetric regions the costs of abatement are fully endogenized in a model calibrated to real world data. Figure 5.2 shows the size of the stable coalition in terms of percentage of world GDP for the different scenarios of global social costs of carbon (SCC) in the policy regime without trade sanctions (*NTRF*). It indicates that with rather low global SCC of 12.5 USD per ton of $CO_2$ a stable coalition covering 58% of world GDP can be maintained.[30] With increasing social costs of carbon the size of the stable coalition decreases. For a global social cost of carbon of 50 USD only a coalition covering 32% of world GDP is stable. This coalition remains stable for a global social cost of carbon of 100 USD.

### Policy Regime *UTRF*: Stable Coalitions with Uniform Tariffs

Introducing trade sanctions against outsiders of the coalition imposes a strong incentive to join. We find this effect, which has been extensively discussed by Nordhaus (2015), in the *UTRF* regime. Figure 5.2 shows the size of the stable coalition for the different tariff-scenarios

[30]We find a rather large stable coalition of 58% of world GDP under *NTRF*. This is due to the assumed Armington structure of international trade (see footnote 29). Furthermore, our discussion on costs and emissions in Subsection 5.6.3 reveals that while the coalition seems quite large, effectively it only achieves an emission reduction of 1% compared to the business-as-usual (see Table 5.4).

from 1% up to 10% for the different assumptions about the global social cost of carbon. For low global social costs of carbon of 12.5 USD the threat of trade sanctions of 1% is already high enough to stabilize the grand coalition. Of course, if the grand coalition is stabilized by means of sanctions no region is actually subjected to the tariffs. All regions are members of the coalition while the trade sanctions serve as a threat for regions in case of leaving the coalition. With higher global social costs of carbon, the tariff rate which is necessary to stabilize the grand coalition increases so that in case of social costs of carbon of 100 USD only a substantial tariff of 10% could stabilize the grand coalition.

**Policy Regime *RTRF*: Stable Coalitions with Tariffs and Retaliation**

Allowing outsiders of the coalition to retaliate with the same tariff rate markedly changes the results (policy regime *RTRF*). Figure 5.2 shows the sizes of stable coalitions in percentage of world GDP for these scenarios. While the grand coalition can still be stabilized by sufficiently high trade sanctions, retaliation reduces the threat of being targeted. As a consequence, in case of social costs of carbon above 12.5 USD the size of stable coalitions that can be maintained with low trade sanctions decreases in comparison to the scenarios without retaliation. For social costs of carbon above 25 USD the effect of retaliation is sufficient to destabilize all possible coalitions for a tariff rate of 1%. More strikingly, in all scenarios with retaliation the non-cooperative outcome is an equilibrium: the non-cooperative solution. In the same way the threat of trade sanctions against outsiders can prevent members from leaving the coalition, retaliatory trade measures can prevent outsiders regions from joining small coalitions that impose trade sanctions on outsiders.

**A Closer Look**

The results for the scenarios with retaliation call for a closer look. The existence of two stable equilibria for almost all of these scenarios raises the question which of the two equilibria might be reached. Although our analysis does not explicitly consider the dynamics of coalition formation, our results deliver some insights regarding this question. Our numerical results mirror our insight from Proposition 5.1.

The threat of being targeted by trade sanctions of coalition members and thus the stabilizing effect of tariffs increases with the size of the coalition as the volume of traded goods that is covered by tariffs increases for outsiders. By the same argument small coalitions are destabilized by retaliatory trade measures of outsiders: in small coalitions members have a high volume of trade with outsiders which makes them prone to retaliation. Retaliatory trade measures then have the potential to incentivize coalition members to leave the coalition to avoid retaliation. As a consequence, small coalitions are internally instable (and externally stable) which means that further regions want to leave the coalition while big coalitions are externally instable (and internally stable) so that further regions want to join the coalition. On the one hand, this means that if an already larger coalition exists, the introduction of trade sanctions could lead to an

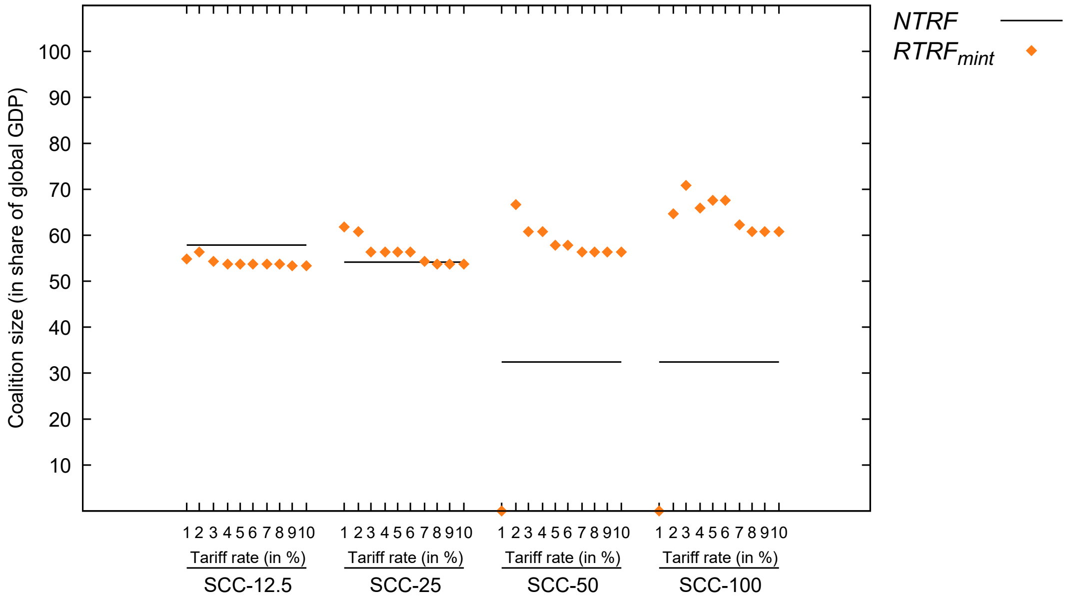


**Figure 5.3:** Percentage share of world GDP of stable coalitions in the policy regime *NTRF* and of the smallest internally stable coalitions under *RTRF* for different assumptions about the global social cost of carbon. $RTRF_{\text{mint}}$ refers to the smallest internally stable coalition under *RTRF* other than the empty coalition.

even bigger and possibly grand coalition, even in the presence of retaliation. On the other hand, starting from a small coalition the introduction of trade sanctions diminishes cooperation and the non-cooperative equilibrium results. In other words: the introduction of both trade sanctions and retaliatory trade measures induce a threshold effect in the coalitional game. Below a certain coalition size the destabilizing effect of retaliation predominates and leads to the non-cooperative equilibrium whereas in coalitions above a certain size the stabilizing effect of trade sanctions enables the formation of even bigger stable coalitions.

Figure 5.3 shows the size of the smallest internally stable coalition (other than the empty coalition) in the scenarios with trade sanctions and retaliation (*RTRF*) and the size of the stable coalition in the absence sanctions (*NTRF*) in percentage of world GDP. These results show that the introduction of trade sanctions and retaliation with an already existing coalition that is stable without sanctions would lead to the non-cooperative equilibrium in most of the scenarios. Only for low global social costs of carbon of 12.5 USD per ton of $CO_2$ and for global social costs of carbon of 25 USD per ton of $CO_2$ with tariffs higher than 7% the introduction of trade sanctions with retaliation could help to stabilize a growing coalition that could ultimately become the grand coalition.

### 5.6.3 Costs and Emissions in Stable Coalitions

We report results on global costs and benefits, global emission changes, and global average $CO_2$ prices in all stable coalitions across our three policy regimes and four assumptions about the global social cost of carbon (SCC). Table 5.4 summarizes the results under *NTRF* and Tables 5.5 and 5.6 show the results for the regimes with uniform trade sanctions (*UTRF*) and with retaliation (*RTRF*).[31] Global welfare is composed of two factors: (i) economic adjustment costs due to the $CO_2$ tax, i.e. the change in real consumption (item Cost CN in the tables); (ii) environmental benefits due to the change in global emissions, i.e. the global emission reduction times the respective global social cost of carbon (Benefit EM). Global welfare is the difference of environmental benefits and economic costs (Hicksian EV).[32] Cost and welfare items are reported as percentage share of business-as-usual GDP. The global average $CO_2$ price is given in USD per ton of $CO_2$, and global emissions are given as percentage change from the business-as-usual.[33]

Under *NTRF* (Table 5.4), we find that cooperation reduces the global emission level by 0.6% to 1.4% compared to the respective business-as-usual. The global average $CO_2$ price is about 30% of the efficient level for SCC-12.5 and decreases to roughly 15% of the efficient level for SCC-100 as the size of the stable coalition is smaller. If we focus on the economic adjustment costs, we find that they are slightly negative under SCC-50. This is again due to the terms of trade.[34] As we move to SCC-100, where we find the same stable coalition as in SCC-50, economic costs have turned positive. The global welfare gain due to cooperation increases with the assumed SCC.

**Table 5.4:** Global cost and emission impacts in stable coalitions under *NTRF*

| | SCC-12.5 | SCC-25 | SCC-50 | SCC-100 |
|---|---|---|---|---|
| Cost CN | 0.005 | 0.010 | -0.001 | 0.003 |
| Benefit EM | 0.005 | 0.013 | 0.011 | 0.039 |
| Welfare | 0.000 | 0.003 | 0.012 | 0.036 |
| $CO_2$ Price | 3.86 | 6.42 | 7.61 | 15.08 |
| Emissions | -1.0 | -1.4 | -0.6 | -1.0 |

Note.— All costs are given as a percentage share of business-as-usual GDP; Cost CN – change in real consumption; Benefit EM – change in global emissions times the global social cost of carbon; Welfare – Hicksian equivalent variation (difference of Benefit EM and Cost CN); $CO_2$ Price – global average price on $CO_2$ emissions in USD/t$CO_2$; Emissions – percentage change in global emissions.

Now we turn to the comparison of effects under *UTRF* and *RTRF*. We find that in each

[31] In the case of *RTRF*, we report outcomes for the largest stable coalitions.

[32] We take a utilitarian (Benthamite) perspective on global welfare accounting where welfare changes of individual regions are perfectly substitutable.

[33] Be aware that each assumption about the global social cost of carbon constitutes a different business-as-usual.

[34] Recall the discussion of Figure 5.1.

constellation where the grand coalition is established, emission reductions are substantial compared to cooperative solutions under *NTRF*: it ranges from 6.8% for SCC-12.5 to 24.9% for SCC-100. In these cases, global welfare improves compared to the business-as-usual, except for SCC-12.5. The reason is initial tax distortions in the business-as-usual: we set the $CO_2$ at the Pigouvian rate irrespective of interactions with pre-existing taxes. For lower assumptions about the externality (SCC), the externality is relatively small compared to initial tax distortions.

**Table 5.5:** Global cost and emission impacts in stable coalitions under *UTRF* and *RTRF* for SCC-12.5 and SCC-25

| | SCC-12.5 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Trf 1% | Trf 2% | Trf 3% | Trf 4% | Trf 5% | Trf 6% | Trf 7% | Trf 8% | Trf 9% | Trf 10% |
| *UTRF* | | | | | | | | | | |
| Cost CN | 0.041 | 0.041 | 0.041 | 0.041 | 0.041 | 0.041 | 0.041 | 0.041 | 0.041 | 0.041 |
| Benefit EM | 0.034 | 0.034 | 0.034 | 0.034 | 0.034 | 0.034 | 0.034 | 0.034 | 0.034 | 0.034 |
| Welfare | -0.007 | -0.007 | -0.007 | -0.007 | -0.007 | -0.007 | -0.007 | -0.007 | -0.007 | -0.007 |
| $CO_2$ Price | 12.50 | 12.50 | 12.50 | 12.50 | 12.50 | 12.50 | 12.50 | 12.50 | 12.50 | 12.50 |
| Emissions | -6.8 | -6.8 | -6.8 | -6.8 | -6.8 | -6.8 | -6.8 | -6.8 | -6.8 | -6.8 |
| *RTRF* | | | | | | | | | | |
| Cost CN | 0.041 | 0.041 | 0.041 | 0.041 | 0.041 | 0.041 | 0.041 | 0.041 | 0.041 | 0.041 |
| Benefit EM | 0.034 | 0.034 | 0.034 | 0.034 | 0.034 | 0.034 | 0.034 | 0.034 | 0.034 | 0.034 |
| Welfare | -0.007 | -0.007 | -0.007 | -0.007 | -0.007 | -0.007 | -0.007 | -0.007 | -0.007 | -0.007 |
| $CO_2$ Price | 12.50 | 12.50 | 12.50 | 12.50 | 12.50 | 12.50 | 12.50 | 12.50 | 12.50 | 12.50 |
| Emissions | -6.8 | -6.8 | -6.8 | -6.8 | -6.8 | -6.8 | -6.8 | -6.8 | -6.8 | -6.8 |
| | SCC-25 | | | | | | | | | |
| | Trf 1% | Trf 2% | Trf 3% | Trf 4% | Trf 5% | Trf 6% | Trf 7% | Trf 8% | Trf 9% | Trf 10% |
| *UTRF* | | | | | | | | | | |
| Cost CN | 0.091 | 0.103 | 0.103 | 0.103 | 0.103 | 0.103 | 0.103 | 0.103 | 0.103 | 0.103 |
| Benefit EM | 0.092 | 0.113 | 0.113 | 0.113 | 0.113 | 0.113 | 0.113 | 0.113 | 0.113 | 0.113 |
| Welfare | 0.001 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 |
| $CO_2$ Price | 22.20 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 |
| Emissions | -9.5 | -11.6 | -11.6 | -11.6 | -11.6 | -11.6 | -11.6 | -11.6 | -11.6 | -11.6 |
| *RTRF* | | | | | | | | | | |
| Cost CN | 0.060 | 0.101 | 0.103 | 0.103 | 0.103 | 0.103 | 0.103 | 0.103 | 0.103 | 0.103 |
| Benefit EM | 0.039 | 0.108 | 0.113 | 0.113 | 0.113 | 0.113 | 0.113 | 0.113 | 0.113 | 0.113 |
| Welfare | -0.022 | 0.007 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 |
| $CO_2$ Price | 14.36 | 24.50 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 |
| Emissions | -4.0 | -11.1 | -11.6 | -11.6 | -11.6 | -11.6 | -11.6 | -11.6 | -11.6 | -11.6 |

Note.— All costs are given as a percentage share of business-as-usual GDP; Cost CN – change in real consumption; Benefit EM – change in global emissions times the global social cost of carbon; Welfare – Hicksian equivalent variation (difference of Benefit EM and Cost CN); $CO_2$ Price – global average price on $CO_2$ emissions in USD/t$CO_2$; Emissions – percentage change in global emissions; Trf – Tariff rate.

Let's turn to the cases where the grand coalition is not achieved. For assumptions about the global SCC of below 100 USD/t $CO_2$, *RTRF* unambiguously entails lower global emission reductions and lower global welfare levels than *UTRF*. Under SCC-100, however, the picture is mixed. For the cases with a tariff rate higher than 6%, where a very high level of cooperation is achieved, global welfare implications are rather similar. For tariff rates of 6% and lower, the comparison of welfare impacts between *UTRF* and *RTRF* hinges on the exact composition of the stable coalition. The coalition is larger under *UTRF* throughout these cases, which translates into a higher $CO_2$ tax inside the coalition. From a global efficiency perspective, this drives a larger wedge between marginal abatement cost inside and outside the coalition. Under *RTRF*, the $CO_2$ tax is lower inside the coalition, but additional trade distortions lead to more emission reductions outside the coalition. As a manifestation of this effect, the global average price for $CO_2$ is higher for a tariff rate of 4% under *RTRF* compared to *UTRF*, although the coalition is smaller. The overall effect plays out positive under *RTRF* for tariff rates between 2% and 4%, where the global welfare impact is greater than under *UTRF*.

**Table 5.6:** Global cost and emission impacts in stable coalitions under *UTRF* and *RTRF* for SCC-50 and SCC-100

| | SCC-50 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Trf 1% | Trf 2% | Trf 3% | Trf 4% | Trf 5% | Trf 6% | Trf 7% | Trf 8% | Trf 9% | Trf 10% |
| *UTRF* | | | | | | | | | | |
| Cost CN | 0.106 | 0.135 | 0.250 | 0.250 | 0.256 | 0.256 | 0.256 | 0.256 | 0.256 | 0.256 |
| Benefit EM | 0.116 | 0.138 | 0.332 | 0.332 | 0.346 | 0.346 | 0.346 | 0.346 | 0.346 | 0.346 |
| Welfare | 0.009 | 0.004 | 0.082 | 0.082 | 0.090 | 0.090 | 0.090 | 0.090 | 0.090 | 0.090 |
| $CO_2$ Price | 24.99 | 29.74 | 48.90 | 48.90 | 50.00 | 50.00 | 50.00 | 50.00 | 50.00 | 50.00 |
| Emissions | -6.0 | -7.2 | -17.3 | -17.3 | -18.0 | -18.0 | -18.0 | -18.0 | -18.0 | -18.0 |
| *RTRF* | | | | | | | | | | |
| Cost CN | 0 | 0.130 | 0.237 | 0.251 | 0.252 | 0.256 | 0.256 | 0.256 | 0.256 | 0.256 |
| Benefit EM | 0 | 0.111 | 0.288 | 0.332 | 0.332 | 0.346 | 0.346 | 0.346 | 0.346 | 0.346 |
| Welfare | 0 | -0.020 | 0.052 | 0.081 | 0.080 | 0.090 | 0.090 | 0.090 | 0.090 | 0.090 |
| $CO_2$ Price | 5.86 | 23.77 | 44.09 | 48.91 | 48.91 | 50.00 | 50.00 | 50.00 | 50.00 | 50.00 |
| Emissions | 0 | -5.8 | -15.0 | -17.3 | -17.3 | -18.0 | -18.0 | -18.0 | -18.0 | -18.0 |
| | SCC-100 | | | | | | | | | |
| | Trf 1% | Trf 2% | Trf 3% | Trf 4% | Trf 5% | Trf 6% | Trf 7% | Trf 8% | Trf 9% | Trf 10% |
| *UTRF* | | | | | | | | | | |
| Cost CN | 0.104 | 0.228 | 0.328 | 0.336 | 0.345 | 0.547 | 0.549 | 0.595 | 0.596 | 0.607 |
| Benefit EM | 0.172 | 0.312 | 0.432 | 0.434 | 0.437 | 0.808 | 0.809 | 0.925 | 0.925 | 0.962 |
| Welfare | 0.068 | 0.084 | 0.104 | 0.098 | 0.092 | 0.261 | 0.259 | 0.330 | 0.329 | 0.355 |
| $CO_2$ Price | 27.49 | 43.24 | 58.51 | 58.56 | 58.61 | 87.09 | 87.12 | 97.49 | 97.49 | 100.00 |
| Emissions | -4.6 | -8.4 | -11.6 | -11.7 | -11.7 | -21.7 | -21.7 | -24.9 | -24.9 | -25.8 |
| *RTRF* | | | | | | | | | | |
| Cost CN | 0 | 0.203 | 0.362 | 0.391 | 0.351 | 0.408 | 0.570 | 0.598 | 0.599 | 0.600 |
| Benefit EM | 0 | 0.328 | 0.504 | 0.523 | 0.351 | 0.423 | 0.814 | 0.926 | 0.926 | 0.927 |
| Welfare | 0 | 0.126 | 0.142 | 0.132 | 0.001 | 0.015 | 0.244 | 0.328 | 0.327 | 0.327 |
| $CO_2$ Price | 11.60 | 36.09 | 57.50 | 62.27 | 46.49 | 55.94 | 87.25 | 97.53 | 97.54 | 97.55 |
| Emissions | 0 | -8.8 | -13.5 | -14.1 | -9.4 | -11.4 | -21.9 | -24.9 | -24.9 | -24.9 |

Note.— All costs are given as a percentage share of business-as-usual GDP; Cost CN – change in real consumption; Benefit EM – change in global emissions times the global social cost of carbon; Welfare – Hicksian equivalent variation (difference of Benefit EM and Cost CN); $CO_2$ Price – global average price on $CO_2$ emissions in USD/t$CO_2$; Emissions – percentage change in global emissions; Trf – Tariff rate.

## 5.7 Conclusion

Former studies of import tariffs as a means to stabilize climate coalitions have concluded that they are an effective mechanism to foster international cooperation. However, most of these studies have relied on the assumption that outsiders are not able to retaliate, i.e. to use trade measures themselves. To close this research gap we use combined analytical and numerical analysis to investigate implications for internal and external stability under three policy regimes: (i) a regime without trade sanctions, (ii) a regime in which coalition members use trade sanctions in the form of uniform import tariffs against outsiders, and (iii) a regime in which coalition members use trade sanctions and outsiders retaliate with uniform import tariffs.

Our analytical model shows that while trade sanctions without the possibility to retaliate might stabilize coalitions, incorporating retaliation entails a "threshold" effect: Below a certain coalition size the destabilizing effect of retaliation predominates and leads to the non-cooperative equilibrium whereas in coalitions above a certain size the stabilizing effect of trade sanctions enables the formation of larger stable coalitions.

For our quantitative assessment we use a standard multi-sector, multi-region CGE model, where regional and global welfare effects due to policy interference is fully endogenized. Our assessment for scenarios with retaliation shows that while it is still possible to maintain larger stable coalitions, also the non-cooperative solution becomes stable. In our simulations, the "threshold" coalition size is well above 50% of world GDP across all assumptions about the global social cost of carbon.

We conclude that the consideration of retaliatory measures substantially decreases prospects for international cooperation through the threat of trade sanctions. Only after a sufficiently large climate coalition has already been formed, the threat of trade sanctions might be an effective stick to establish the grand coalition.

## 5.8 Appendix

### 5.8.1 Proof of Lemma 5.1

ad 1.

We assume here that the coalition size $k$ is a continuous variable, effectively allowing for arbitrary shares of countries to be part of the coalition.[35] Inserting (5.4) and (5.2) in the

[35]The same results could be obtained by keeping $k$ integer-valued and examine the differences $\Phi^{NTRF}(k) - \Phi^{NTRF}(k-1)$ for $k \geq 1$ for monotonicity. We opt for the nicer representation of a continuous $k$ and using the derivative of $\Phi^{NTRF}$.

stability function (5.6) leads to

$$\begin{aligned}\Phi^{NTRF}(k) = & \\ & b\left(kC^{'-1}(kb) + (N-k)\,C^{'-1}(b)\right) - C\left(C^{'-1}(kb)\right) \\ & -b\left((k-1)\,C^{'-1}\left((k-1)\,b\right) + (N-k+1)\,C^{'-1}\left(b\right)\right) + C\left(C^{'-1}\left(b\right)\right)\end{aligned} \tag{5.11}$$

Differentiation of (5.11) with respect to $k$ leads to

$$\frac{\partial \Phi^{NTRF}(k)}{\partial k} = bC^{'-1}(kb) - bC^{'-1}\left((k-1)\,b\right) - bb\,(k-1)\,\frac{\partial C^{'-1}\left((k-1)\,b\right)}{\partial k}. \tag{5.12}$$

Concavity of $C^{'-1}$ implies

$$C^{'-1}(kb) - C^{'-1}\left((k-1)\,b\right) \leq b\frac{\partial C^{'-1}\left((k-1)\,b\right)}{\partial k}, \tag{5.13}$$

so that (5.12) is negative for all $k \geq 1$.

ad 2.

For a coalition of two countries the stability function is

$$\begin{aligned}\Phi^{NTRF}(2) =& b\left(2C^{'-1}(2b) + (N-2)\,C^{'-1}(b)\right) - C\left(C^{'-1}(2b)\right) \\ & - b\left(C^{'-1}\left(b\right) + (N-1)\,C^{'-1}\left(b\right)\right) + C\left(C^{'-1}\left(b\right)\right) \\ =& 2b\left(C^{'-1}(2b) - C^{'-1}(b)\right) - \left(C\left(C^{'-1}(2b)\right) - C\left(C^{'-1}\left(b\right)\right)\right).\end{aligned} \tag{5.14}$$

Since

$$2b = C^{'}\left(C^{'-1}(2b)\right) \tag{5.15}$$

this can be written as

$$\begin{aligned}\Phi^{NTRF}(2) = C^{'}\left(C^{'-1}(2b)\right)\left(C^{'-1}(2b) - C^{'-1}(b)\right) & \\ - \left(C\left(C^{'-1}(2b)\right) - C\left(C^{'-1}\left(b\right)\right)\right) &\end{aligned} \tag{5.16}$$

$C$ is strictly convex so that

$$C^{'}\left(C^{'-1}(2b)\right)\left(C^{'-1}(2b) - C^{'-1}(b)\right) > \left(C\left(C^{'-1}(2b)\right) - C\left(C^{'-1}\left(b\right)\right)\right) \tag{5.17}$$

and thus $\Phi^{NTRF}(2) > 0$. $\square$

### 5.8.2 Proof of Proposition 5.1

The net stability function reads as

$$\Delta\Phi^{RN}(\theta, k) = \Phi^{RTRF}(\theta, k) - \Phi^{NTRF}(k) = (N - 2k + 1)(\beta(\theta) - \zeta(\theta)). \quad (5.18)$$

Differentiating with respect to coalition size $k$ gives us

$$\frac{\partial \Delta\Phi^{RN}(\theta, k)}{\partial k} = -2\beta(\theta) + 2\zeta(\theta). \quad (5.19)$$

We can assume that trade sanctions decrease global welfare due to trade distortions – recall the discussion in section 5.3. Thus, the total benefits from trade sanctions are lower than the total costs which, in our specification, boils down to the condition that benefits from putting tariffs on one trade-flow are lower than the costs, i.e. $\beta(\theta) < \zeta(\theta)$. Thus, we see that $\frac{\partial \Delta\Phi^{RN}(\theta,k)}{\partial k} > 0$ and that $\Delta\Phi^{RN}(\theta, k)$ has a single zero at $k = \frac{(N+1)}{2}$ for all $\theta > 0$. $\square$

# 6 | What the Economics of Climate Change Mitigation May Tell on Transnational Adaptation

## 6.1 Introduction

Previously a "taboo" within climate policy and research (Pielke et al., 2007), climate adaptation has gathered momentum in the last few years, acknowledging that climate change will be unavoidable even under the most ambitious mitigation goals.[36] Most recently, the Paris Agreement has put further emphasis on climate adaptation: it has promoted it from a fundamentally local endeavor to the object of international cooperation (Lesnikowski et al., 2017). Up to now, the international dimension of climate adaptation has been limited to environmental justice considerations related to adaptation finance (Grasso, 2010; Paavola and Adger, 2006; Persson, 2011). This chapter contributes to broadening such perspective by exploring the case where adaptation by some countries affect other ones.

In such a case, adaptation resembles the problem structure at the core of climate change mitigation economics: opportunistic free-riding on other nations' efforts to address a common problem. It is thus worthwhile to explore findings from more than two decades of economic research on IEAs for climate change mitigation (from here on referred to as "IEA literature"), and see what implications they may have for the sort of adaptation envisioned here. We do so with reference to climate-change induced eutrophication in the Baltic Sea – an issue which is paradigmatic both as a case where adaptation by some countries affects other ones, and for its similarity with climate change mitigation challenges.

Applying insights from the IEA literature leads to rather counterintuitive implications for governance architectures in the Baltic Sea. Conveniently, such implications fit particularly well the transnational adaptation agenda as they involve multiple nation states and a plurality of governance architectures. The chapter is structured as follows: Section 6.2 conceptualizes cross-boundary adaptation spillovers and establishes a conceptual bridge to the IEA literature.

[36]This chapter is based on Roggero et al. (2018).

Section 6.3 explores the Baltic Sea case and applies IEA insights to its adaptation problem. Section 6.4 discusses the chapter's findings at a more general level. Finally, Section 6.5 provides some concluding remarks.

## 6.2 Literature Review

Central to the present work is the concept of "cross-boundary adaptation spillover": it describes externalities that occur if adaptation measures by one country affect other countries. Relying on that, the present section aims at establishing conceptual bridges between transnational adaptation and the IEA literature. Doing so requires several steps, addressing whether: 1) adaptation has spillovers; 2) such spillovers are cross-boundary; 3) cross-boundary adaptation spillovers generate a problem structure that resembles climate change mitigation; and 4) it is possible to leverage IEA knowledge in order to address cross-boundary adaptation spillovers. With that in mind, the present section features four subsections, respectively providing arguments in support of each of the four steps above. The remainder of this subsection, instead, introduces climate adaptation in a transnational context.

Climate adaptation describes the many ways individuals, groups and societies adjust to the observed and/or expected end of a stationary climate (Smit and Wandel, 2006). Within such definition, scholars distinguish "spontaneous" adaptation by individuals from "planned" adaptation as a part of climate policy (Smit and Pilifosova, 2001). The present work focuses on planned adaptation. Scholarly debates in these respects have focused on the appropriate "level" of politico-administrative organization at which adaptation is best delivered (Dodman and Satterthwaite, 2008; Few et al., 2007). They are thus anchored to an understanding of adaptation as a task for either local or national governments – at best something requiring cooperation between the two. Adaptation, in other words, has been so far understood as a domestic affair, without any international dimension.

The reader may object the international dimension of climate adaptation exists, and pertains adaptation finance (Barrett, 2013; Klein, 2010). Adaptation finance, however, is based on a "pollutionist" perspective (Persson, 2011) in which certain nations care for adaptation in and by other nations only on the basis of moral commitment. The role of adaptation within the Kyoto Protocol reflects this very same understanding (Grasso, 2010). By contrast, the present work is based on the premise that climate adaptation by one country affects other ones (Liverman, 2016; Moser and Hart, 2015). Here, adaptation acquires an international dimension for reasons other than moral commitment. Most importantly, there is a different problem structure at play, where moral commitment leaves way to self-interest and, possibly, opportunism.

Acknowledging this, Benzie et al. (2016) propose the concept of transnational adaptation. It is defined as adaptation taking place across the boundaries of nation states and involving non-state actors to some degree. Calling the "domestic", national-to-local understanding of climate adaptation into question, such a definition acknowledges a more complex and heterogeneous set of interactions and governance arenas than previously accounted for (Benzie et al., 2016).

Against this background, the present contribution seeks to advance our understanding of the link between the problem structure inherent to transnational adaptation and the institutional arrangements shaping it. It does so by tapping into the IEA literature – a body of scholarly work centered on the same problem structure as the one identified herewith, where climate adaptation acquires an international dimension because of cross-boundary spillovers. The IEA literature may thus deliver insights that apply to transnational adaptation as well. Crucially, such insights will fit with the transnational adaptation agenda as they open up to different architectures and multi-level arrangements. To that end, the following subsections establish a conceptual bridge with the IEA literature.

### 6.2.1 Does Adaptation Have Spill-Overs?

The first step in establishing a bridge between transnational adaptation and the IEA literature concerns the question whether adaptation has spillovers altogether. Adaptation scholars have so far had little interest in the possibility that adaptation by some may have spillovers (Benzie et al., 2016). That is not surprising: scholars addressing "barriers" to adaptation (Eisenack et al., 2014; Moser and Ekstrom, 2010) have shown that adaptation has so far taken place too little rather than too much and/or in the wrong place. Spillovers (cross-boundary or not) are more likely to become evident once adaptation has been implemented at a sufficient scale, not before.

Evidence of spillovers from adaptation can nevertheless be found, with reference to the concept of "no-regret" adaptation measures: adaptations that are beneficial regardless of the actual on-setting of the respective climate impacts. Typical examples are green areas in cities that, next to protecting citizens against heat waves (Oberndorfer et al., 2007; Bowler et al., 2010), also have a recreational value (James et al., 2009; Tzoulas and James, 2010), together with positive effects on e.g. local air quality (Bolund and Hunhammar, 1999; Jim and Chen, 2008). These measures qualify as "no-regret" in light of the effects they have apart from their main purpose of reducing climate vulnerability. They do have spillovers, then.

Spillovers from adaptation, furthermore, are not always positive. The concept of maladaptation (Klein et al., 2007; Barnett and O'Neill, 2010; Juhola et al., 2016) describes situations where adaptation takes place, but fails to reduce vulnerability. Adaptation efforts can end up shifting vulnerability rather than reducing it, and that as a product of unintended effects and external spillovers (Atteridge and Remling, 2018).

Several examples can be found in the literature. Flood control measures in the Mekong delta allow for agricultural harvesting to continue well into the flood season, leading however to fish decline, and to the loss of the fertilizing function of the floods (Birkmann, 2011; Chapman et al., 2016). The poor design of coastal erosion measures in Cape Town, South Africa, led to the very same measures (sandbags), breaking apart and releasing plastic debris into the coastal environment (Magnan et al., 2016). These examples support the view that adaptation may have negative spillovers as well.

## 6.2.2 Are Adaptation Spillovers Cross-Boundary?

The second step in establishing a bridge between transnational adaptation and the IEA literature lies in the cross-boundary dimension of adaptation spillovers. Evidence for that is available too. Consider adaptation measures such as the urban green mentioned above. The very same climate impacts (e.g. heat waves, heavy rains) can also be tackled through green belts, wetlands and other types of natural habitats in the outskirts of urban centers – an approach that goes under the header of "ecosystem-based adaptation" (Roberts et al., 2012; Wamsler et al., 2014). Next to addressing climate impacts, ecosystem-based adaptation contributes positively to global public goods such as bird migration and biodiversity (Jones et al., 2012; Munang et al., 2013). There are thus adaptations with cross-boundary spillovers.

Negative cross-boundary spillovers can be found too. Raising dykes to tackle floods tends to shift the problem further downstream. That is particularly problematic in the case of transboundary rivers, which are a typical case for international cooperation (Mitchell, 2006). Internationally shared resources such as transboundary rivers are certainly not immune to the need to adapt to climate change (Kistin and Ashton, 2008; Goulden et al., 2009). At the very least, adaptation is constrained by the architectures shaping the shared management of such resources. Unless adaptation is negligible viz. such arrangements, adaptation measures are bound to be subject to the same degree of international cooperation.

An easy objection may be that adaptation spillovers affecting internationally shared resources are likely to be negligible. Evidence is available that this is not the case. One good example is the Baltic Sea. Rivers flowing into it are rich in nutrients from agriculture (Ducrotoy and Elliott, 2008). Climate change will alter precipitation patterns across Baltic states (Kundzewicz, 2009), increasing nutrient runoff from agriculture, worsening the state of their inland waters, and increasing nutrient loads into the Baltic Sea. Unless adaptation takes place, mainly in the form of changed agricultural practices and wetland restoration in the countries at stake, the Baltic Sea may experience up to 18% more natrum and 21% more phosphor under particular scenarios (Huttunen et al., 2015), which doesn't seem negligible. The Baltic Sea case will be addressed in detail in Section 6.3. For the moment, it is enough to bear in mind that cross-boundary spillovers from adaptation action are a possibility.

### 6.2.3 What Is the Problem Structure in Mitigation Economics?

The third step in establishing a bridge between transnational adaptation and the IEA literature concerns the problem structure. We hereby refer to the game theoretic literature on IEAs. Since the early 1990s, this branch of the climate economics literature studies international cooperation for climate change mitigation (Carraro and Siniscalco, 1993; Barrett, 1994). Based on concepts from the theory of economic cartels (d'Aspremont et al., 1983; Chander and Tulkens, 1995) it frames IEAs as stable coalitions whose members contribute to a public good. Later on, the analysis was extended to different policy measures that may help to reach an outcome as close as possible to the social optimum (Marrouch and Ray Chaudhuri, 2016).

The problem structure thus analysed revolves around the provision of a pure public good. In a mitigation setting, the abatement of greenhouse gas emissions is costly (Stern, 2007), and the benefits also depend on the abatement of others (Pachauri et al., 2014). That already disincentives abatement. Furthermore, other countries can free-ride on the efforts of those countries that do reduce their emissions, sharing the thus obtained benefits (Hoel, 1991). An important mechanism for that is carbon leakage, which means that carbon-intensive industry relocates production to countries with fewer restrictions (Felder and Rutherford, 1993). That disincentives abatement even further. Local co-benefits, instead, can motivate actors to abate (e.g. Bollen et al., 2009; Harlan and Ruddell, 2011), shifting the problem structure to one of an impure public good.

In the absence of a supranational authority prescribing a certain degree of effort by all beneficiaries of climate change mitigation, progress relies on voluntary agreements, involving coalitions of countries willing to abate. Uncertainty here takes the shape of countries possibly seeking renegotiation at later stages (Weikard et al., 2010). Against this background, the literature addresses questions relating to the size and stability of such coalitions, in general as well as in light of specific policy instruments being used. As we will show for the case of the Baltic Sea, in presence of cross-boundary adaptation spillovers, a problem structure emerges that resemble the one sketched herewith. If the problem structure is similar, we argue, insights from the one context can be transferred analogously to the other.

### 6.2.4 What Insights Can Be Drawn from the IEA Literature?

The fourth step in establishing a bridge between transnational adaptation and the IEA literature concerns the insights to be borrowed. The general finding is that, because of free-riding, coalitions will tend to be small and achieve little. This is the "paradox of cooperation": stable coalitions achieve little when cooperation matters most in terms of improvement over the non-cooperative outcome (Carraro and Siniscalco, 1993; Finus and McGinty, 2015). The literature has gone a long way since then, though, exploring several approaches to overcome this problem. These are inter alia: coalition structures, side-payments, issue-linkage, and trade sanctions.

Concerning coalition structures, a notable example here is that of "climate clubs". Countries can form coalitions that are not exclusive but coexist, i.e. several coalitions can be formed in parallel. Both theoretical (e.g. Asheim et al., 2006, Chapter 3) and simulation studies (e.g. Osmani and Tol, 2010; Bosello et al., 2003; Eyckmans and Finus, 2006) find, that under certain circumstances, multiple, small coalitions may lead to higher participation and greater supply of the public good compared to what would have been achieved with a single coalition. Each of the formed small coalitions decides to contribute to the public good, so that the sum of the contributions exceeds that of a single coalition (which would be subject to the "paradox of cooperation"). Here there are clear implications for the Baltic case, as the reader will see in Section 6.3.

Side-payments were introduced in seminal papers by Hoel (1992a) and Carraro and Siniscalco (1993). They showed that welfare transfers between countries can increase cooperation. When benefits from abatement are asymmetric across countries, those with high benefits from abatement can increase the size of the coalition by providing side-payments to countries with lower benefits from abatement, leading to higher levels of global abatement and welfare (Barrett, 2001; Fuentes-Albero and Rubio, 2010; McGinty, 2007; Dellink, 2011; Lessmann et al., 2015).

As an alternative to side-payments, issue linkage can also increase cooperation. Precondition for that is the presence of different sources of externalities between the countries involved, so that cooperation on one issue can be made conditional to cooperation on another one (Folmer and Mouche, 1994). Interestingly, this needs not to be of environmental nature (Folmer et al., 1993). Care is due, however, since linkage may as well decrease cooperation (Carraro and Marchiori, 2004). Issues that seem particularly suitable for linkage with environmental negotiations include research and development (e.g. Carraro and Siniscalco, 1995; Katsoulacos, 1997), international debt swaps (Mohr, 1995; Mohr and Thomas, 1998) and trade sanctions (e.g. Barrett, 1997a).

The latter case has received particular attention recently (Barrett, 2011; Lessmann et al., 2009; Nordhaus, 2015; Böhringer et al., 2016, Chapter 5). Here the idea is to apply trade sanctions to encourage participation in the IEA. By including trade penalties against outsiders in the climate agreement countries are incentivized to join. Lessmann et al. (2009) and Nordhaus (2015) find that already small penalties can be sufficient to stabilize a large climate coalition with high abatement levels. If retaliation occurs, however, trade sanctions may prove counterproductive (see Chapter 5).

## 6.3 Applying Mitigation Insights to an Adaptation Case: Eutrophication in the Baltic Seas

The previous section has established a bridge between transnational adaptation and the IEA literature. Doing so has highlighted four approaches that could be applied to adaptation cases in the presence of cross-boundary spillovers: coalition structures, side-payments, issue-linkage, and trade sanctions. The present section provides an illustrative example of the way these approaches could be applied to an actual case: eutrophication in the Baltic Sea (Section 6.3.1). Emphasis will be put to present the case 1) as an adaptation case; 2) with cross-boundary spillovers; in order to 3) outline the resulting problem structure and 4) compare it to the one mitigation economics is concerned with. The arrangements in place in the Baltic context will then be briefly presented (Section 6.3.2), and subsequently analysed through the lenses of the IEA literature (Section 6.3.3). As the emphasis lies on Section 6.3.3, Section 6.3.1 and 6.3.2 will necessarily be kept at a minimum. Detailed accounts on the governance architectures in place at the Baltic Sea can be found in Gilek et al. (2016) and Hassler (2017).

### 6.3.1 The Problem Structure

The physical environment of the Baltic Sea is under severe anthropogenic pressure (Johannesson et al., 2011). Eutrophication due to agricultural nutrient runoff is "perhaps the biggest problem confronting the Baltic" (Ducrotoy and Elliott, 2008). Climate change makes things worse: by increasing precipitations, it increases nutrient runoff from the fields to the rivers and towards the sea (Andersson et al., 2015; Graham, 2004; Friedland et al., 2012). Simulations foresee change in nutrient loads between -9% and +18% for natrum and between -7% and +21% for phosphor (Huttunen et al., 2015). Crucially, variation depends on the socio-economic scenarios and modeling uncertainties, but adaptation can significantly reduce the resulting impact upon the Baltic Sea (Huttunen et al., 2015).

The nutrients at stake originate from agriculture and reach the Baltic Sea through the inland and coastal waters of the different states within the drainage basin. The available options for reducing how much nutrients reach the sea mainly consist of preventing nutrient leakage at the source (that is, less agriculture or at least less fertilizers), or creating wetlands that absorb nutrients as close as possible to the source. Countries have an interest in doing so, because nutrients from their own agriculture affect their own inland waters first. Agricultural nutrients are thus a domestic nuisance before they even affect the Baltic Sea. To the extent climate change leads to increased precipitations, and nutrient loads increase because of that, adaptation corresponds to additional restrictions in the use of fertilizers, and to the creation of additional wetlands absorbing the additional load.

Let us now gauge the problem structure. Consider the individual Baltic state's decision whether to curb nutrient runoff from agriculture. For each state, abatement costs stand against eutrophication-related losses in the environmental quality of both inland waters and the Baltic Sea as a whole. Benefits from cleaner inland waters (e.g. scenic beauty, tourism revenues, inland fisheries), constitute a private good for the individual state in which they are located. Benefits derived from the environmental quality of the Baltic Sea constitute instead a public good affected by the cumulative effort of all Baltic states.

Facing a tradeoff between abatement costs and environmental benefits, Baltic states can make their choices. At present, efforts vary, with Finland and Sweden at the more proactive end of the spectrum, and Russia at the more reluctant one (Hassler, 2017). Results are cumulatively not enough to significantly decrease nutrient loads in the Baltic Sea (Elmgren et al., 2015). Against such status quo, climate change alters precipitation patterns, raising the amount of nutrients being discharged into the water bodies and thus increasing the underprovision of eutrophication abatement. Adaptation represents the efforts necessary to counterbalance the effects of the additional nutrient runoff caused by climate change.

Let us now consider the different elements of the problem structure just laid out. These are: a public good (1); a baseline level of anthropogenic pollution (2); private benefits from the abatement of such pollution (3), which are not enough to avoid underprovision (4). Since full abatement in one state would not compensate for no abatement in another state, there is a need for cooperation (5) and a corresponding risk of free-riding (6), since every country can hold back abatement and enjoy the fruits of the efforts of the other states. Finally, the nuisance at stake is problematic per se (7), but becomes even more problematic in light of future trends: increased precipitation due to climate change (8).

The reader will have noted that the problem structure is more complex than that of a pure public good. The same holds climate change mitigation, though. Next to the atmosphere as a public good (1) and the corresponding collective action challenges (5, 6), climate change mitigation also features: baseline CO2 emissions (2); private benefits through e.g. better air quality (3), leading however to insufficient abatement (4); and future trend worsening the problem: demographic and socioeconomic growth (8). In presence of cross-boundary spillovers, the problem structure of adaptation resembles thus that of climate change mitigation.

### 6.3.2 Baltic Sea Governance Arrangements from a Mitigation Economics Perspective

Having laid out the basic elements of the eutrophication problem in the Baltic Sea, some words are due on the institutional arrangements in place. Almost all of the Baltic Sea falls within the Exclusive Economic Zones of the various countries around its coasts: Sweden, Denmark, Germany, Poland, Russia, Lithuania, Estonia, Latvia, and Finland (Backer et al., 2010). All such countries belong to the European Union (EU), with the notable exception of Russia. Furthermore, about half of them are former Soviet countries, with a history of lax environmental regulation and intensive agricultural production. The EU accession has dramatically improved environmental standards in Poland, Lithuania, Estonia, Latvia, yet not enough to lower the concentrations of nutrients in the Baltic (Elmgren et al., 2015).

The major, but not exclusive presence of EU Member states in the Baltic Sea region leads to a complex architecture shaping the management of the sea's waters. A central piece of legislation is the EU's Water Framework Directive (WFD), requiring the achievement of a Good Ecological Status in the whole basin, including both Baltic Sea's waters and the inland water bodies of the surrounding member states. Furthermore, the EU has developed a regional approach to the management of the Baltic Sea. First of its kind, the Baltic Sea Region Strategy (BSRS) consists of a framework coordinating EU projects addressing the state of the Baltic Sea, ideally facilitating cooperation in the region.

Within the BSRS, a recently updated Action Plan spells out goals and objectives for the region, water quality and eutrophication featuring prominently therein. It has however a non-binding character. Similarly, the Helsinki Convention spells out goals and objectives for the management of the Baltic Sea, giving a prominent role to combating eutrophication, again without a binding character. Compared to the BSRS, the Helsinki Convention and its secretariat (the Helsinki Commission: HELCOM) have the merit of including Russia. Furthermore, the polluter-pays-principle and the precautionary principle introduced therein never translated into operational management tools (Ducrotoy and Elliott, 2008).

In all of the above, the effects of climate change upon the Baltic Sea and the states surrounding it are featured only peripherally (Backer et al., 2010; Elliott et al., 2015). In the absence of coordinated and agreed-upon adaptation measures, the governance architecture addressing cross-boundary adaptation spillovers is the one resulting from the interplay of WFD, BSRS and HELCOM. Specifically, the question emerges whether national adaptations are somehow coordinated with an eye on their effects upon the Baltic Sea eutrophication problem. Hassler (2017) provides evidence in these respects: his analysis of national implementation plans addressing eutrophication under the HELCOM Baltic Sea Action Plan shows little willingness to cooperate among signatories.

Karlsson et al. (2016) and Elmgren et al. (2015) come to similar conclusions, while Bengtsson (2009) points at the lack of an external perspective, particularly concerning the role of Russia. Furthermore, Piwowarczyk et al. (2012) show how key decision-makers are preoccupied with more pressing social and economic issues, deeming climate change as secondary. As a result, the available governance architecture is presently only able to achieve consensus on abstract strategies and on the need of a dialogue on national implementations. Ambitious initiatives seem out of reach (Backer, 2011).

### 6.3.3 Applying an IEA Perspective

Having sketched both the problem structure and the institutional arrangement, it is now possible to explore the implications of coalition structures, side-payments, issue-linkage, and trade sanctions for the Baltic case. In terms of coalition structures, the counterintuitive insight is that multiple small arrangements are superior to a single large one that does not involve everybody. Translated for the Baltic context, it implies that multiple small groups of Baltic states may possibly achieve more than a single, large, but not all-encompassing group. Against this background, two main questions arise.

First, the very existence of BSRS hints at a new development of EU governance towards regional arrangements. In these respects, the IEA literature raises the question whether a more effective cooperation could be sought among some of the Baltic states, creating sub-regional arrangements. Note how this goes against the received wisdom of resource arrangements "fitting" the geographical extent of a given resource as much as possible (Young, 2002; Moss, 2012). It also goes counter the expectations of regional public good scholars (Sandler, 1998, 2006) justifying larger jurisdictions (e.g. through economies of scope), not smaller ones. By contrast, from an IEA perspective, BSRS could be surprisingly too large.

Second, BSRS has the same scope of HELCOM, minus Russia. One could thus look at BSRS as the smaller but stable coalition mitigation economics points at. By the same token, other sub-coalitions within HELCOM could be studied. The most notorious source of instability there is the rift between EU and Russia. Paradoxically, the EU-Russia relations may overshadow other distinctions among HELCOM signatories which may lead to stable coalitions. Candidates could be the differentials in marginal costs across states, the differentials in marginal private benefits from abatement, or the actual ability to free-ride.

Side-payments can be a source of stability if costs vary substantially across countries. Indeed, a few studies find scope for addressing eutrophication in the Baltic region through side-payments (Markowska and Żylicz, 1999; Gren, 2008), and side-payments do appear in the HELCOM context (Hassler, 2017), albeit with little political support. A different take could focus on BSRS as a channel towards EU subsidies. BSRS receives project proposals from the countries' local and regional administrations and redirects them to the EU. It is not proactively crafting them. If steep costs make countries less proactive, supporting proactive countries may effectively channel funds where costs are low, not high. If one did exactly the opposite, the resulting side-payments may indeed create stability and overall effort.

Political and legal feasibility aside, the IEA literature also suggests that there may be scope for "outsiders" to use side-payments to motivate specific EU countries to pursue adaptation within BSRS, if doing so proves more cost-effective than the available domestic options. If costs are prohibitively high in Russia and Poland, these countries could still consider contributing to adaptation through side-payments to e.g. Latvia, Lithuania or Estonia. They will not reap the private benefits of cleaner inland waters, but they may still protect their own fishing fleets from the costs of additional eutrophication caused by climate change.

Issue-linkage, in the context of the Baltic Sea, would entail tying cooperation in other areas to the cooperation achieved in combating eutrophication. It presupposes that other concerns (environmental or not) may be sufficiently (more) valuable to free-riders to motivate them to contribute. To an extent, issue-linkage may already be at play in the Baltic: EU accession has been functional in the implementation of EU environmental regulations in eastern European countries (Kay, 2014; Křenová and Kindlmann, 2015), and traces of that can be found in the HELCOM process too (Hassler, 2017).

From a different angle, issue-linkage has interesting implications for BSRS, which serves as a coordination platform for all Baltic issues, and was built around the ecosystem approach (Backer et al., 2010). Issue-linkage is certainly compatible with the ecosystem approach. It provides however an additional suggestion: there may be a merit in linking adaptation strategies to completely unrelated issues, without any ecological interdependencies (and thus outside the scope of the ecosystem approach). The only important precondition would be that the interests of the involved parties are such, that they prevent free-riding.

Finally, trade sanctions would correspond, in the Baltic context, to imposing higher tariffs and/or bans on products from states that fail to adapt to eutrophication. This seems to be the least applicable approach and is reported here only for the sake of completeness. Applying tariffs inside the EU seems hardly compatible with European law. On the Russian front, instead, trade sanctions are a reality (at the time of writing), but concern much bigger geopolitical issues (e.g. Crimea's annexation by Russia, Iran's nuclear program) than those addressed here.

## 6.4 Discussion

### 6.4.1 Summary of the Findings

Departing from the paradigmatic case and carefully formulating lessons for adaptation in presence of cross-boundary spillovers, the core insights gained by applying an IEA perspective are the following:

- Multiple coalitions by few, motivated countries and/or countries in similar conditions may achieve more than a large coalition involving most affected parties but marred by free-riding.

- Side-payments should target countries that are not proactive, rather than rewarding countries that already proactive. National and international adaptation funding schemes may be reconsidered accordingly.

- As an alternative to pursuing integrated strategies, transnational adaptation could be linked to international cooperation on areas with no biophysical link to the recipients of adaptation.

- Trade sanctions feature may be used to push countries to provide adaptation with cross-boundary spillovers; their geopolitical costs do not seem commensurate to the gains they can achieve, though.

Given the explorative character of the present work, caution is due. The following subsection articulates therefore potential biases and limitations of the analysis attempted herewith.

### 6.4.2 Conceptual and Methodological Limitations

A first limitation is that the analysis is limited to cross-boundary adaptation spillovers. Transnational adaptation is likely to be more heterogeneous than adaptation with cross-boundary spillovers. An assessment of such heterogeneity is necessary before claiming that the analytical similarities with the IEA literature hold generally. Future research can provide such an assessment, e.g. through a systematic review of potentially transnational adaptation cases.

A second, more serious limitation is that insights from the IEA literature were mostly derived by solving mathematical game theoretical models, not by testing theories with observational data. The limitation here is only apparent, though. The application of IEA insights to adaptation cases would need to be tested empirically regardless of the empirical underpinning of the IEA literature. Conversely, validation of IEA findings in the adaptation realm would not be a substitute for empirical explorations in mitigation settings.

Another limitation comes from the possibility that analytical similarities disappear as soon as the analysis is carried out at a greater level of detail. This is unavoidable. The takeaway is thus that at a general level, both mitigation and transnational adaptation may contribute to a unified overarching theory of how states deal with public goods; more refined theories will instead be problem-specific. This is potentially true even among different instances of transnational adaptation: at a closer look, the role of e.g. coalitions may prove to be crucial in a marine governance setting but fully irrelevant in a biodiversity one. Further research will tell.

### 6.4.3 Policy Implications

Potential implications for the Baltic Sea Region have been spelled out in Section 6.3. The question at this point is what practitioners may generalize from that. In the eyes of a practitioner, a certainly intriguing message is that, if all countries cannot be brought on board, it is better to go for deep and narrow agreements than to go for ones that are shallow and broad. In a context in which the EU becomes open towards regional arrangements, not having to reach an agreement with all parties involved, but just with some, has the potential to significantly lower the transaction costs connected with enacting problem-solving policies: it would allow for far reaching cooperation agreements among groups of states rather than slow and limited arrangements that have to apply to all.

Going for small coalitions as opposed to striving towards agreements shared by all parties involved also seems to grant a stronger role to soft-power, lobbying and ultimately informal arrangements as opposed to hard law and formal commitments. This is not uncommon in an EU-setting, and certainly liberating from the point of view of those practitioners who have to broker deals between national governments. Practitioners will certainly be aware, however, of the costs such an approach has in terms of legitimacy, accountability and transparency.

### 6.4.4 Implications for Research

Correctly identifying the conceptual space in which this work locates itself required a rather long chain of thought, addressing whether: 1) adaptation has spillovers; 2) such spillovers are cross-boundary; 3) cross-boundary adaptation spillovers generate a problem structure that resembles climate change mitigation; and 4) it is possible to leverage mitigation knowledge in order to address cross-boundary adaptation spillovers. Adaptation research, including climate economics (see Scrieciu et al., 2013), has so far largely ignored point 1; point 2 has only recently started being acknowledged (see Benzie et al., 2016); point 3 and 4 are the main thrust of the present work, which is an exploratory, not a consolidating one. The four points are therefore gaps future research could explore. We address them individually.

Concerning point 1, adaptation spillovers are not completely new, but they are not high on the agenda either. If this is due to the little progress of adaptation on the ground, things are bound to change. Climate change will not be halted and adaptation is bound to become increasingly frequent, possibly as disaster risk reduction. The more adaptation happens on the ground, the likelier adaptation spillovers will manifest themselves, supporting the agenda laid down herewith. The transnational adaptation agenda has thus the potential to anticipate future developments and lay down a few seminal contributions on the matter.

Spillovers from adaptation are only relevant here if they are cross-boundary (point 2). Future research will tell whether the incidence of transnational adaptation viz. purely local adaptation is substantial, or whether transnational adaptation represents a niche. More interesting is the question whether cross-boundary adaptation spillovers will prove to be non-negligible. Systematically reviewing the available literature will allow to address that question. Ultimately, though, it will be dedicated biophysical assessments that provide a conclusive answer. These may never come about if scholars do not challenge the received wisdom that adaptation is a purely domestic phenomenon.

Thirdly, the present analysis has relied upon mitigation economics in terms of its findings. These have been applied to the problem at hand after comparing problem structures. The basic assumption underlying such procedure is that, as long as empirically different problems are analytically similar, findings are generally applicable. Future research could carry out the same analysis at the level of the actual models rather than at the level of the findings. Doing so would allow to verify up to which point mitigation and cross-boundary adaptation spillovers are analytically identical (point 3). Fourthly, further research in this area could spell out the technical dimension of "translating" economics models from mitigation to adaptation, identifying gaps, pitfalls, low-hanging fruits and, of course, benefits. More importantly, it would be able to explore actual mechanisms, verify the empirical plausibility of the assumptions underneath the "translated" models, and provide a nuanced approach to their general applicability and to the transferability of their findings (point 4).

## 6.5 Conclusions

The present chapter has addressed climate adaptation in the presence of cross-boundary spillovers. In presence of cross-boundary spillovers, adaptation presents a problem structure similar to that of climate change mitigation. For the last two decades, the economic literature on IEAs has explored that problem structure. It becomes thus worthwhile to explore its findings and see what implications they may have for adaptation.

Next to reviewing the relevant literature, this chapter has provided an empirical illustration with reference to climate-induced eutrophication in the Baltic Sea. After showing the similarity with the problem structure of climate change mitigation, the present institutional arrangements in the Baltic Sea region were explored through the lenses of the IEA literature. Doing so has raised a number of implications for the governance of the Baltic Sea.

Focusing on coalition structures, side-payments, issue-linkage, and trade sanctions, the analysis has proposed a different perspective on how to address the eutrophication problem in the Baltic Sea. Most interesting is the possibility to that, under certain circumstances, arrangements may have a merit even when they do not involve all Baltic states. Integrative arrangements, furthermore need not to be limited to addressing ecologically interdependent resources.

Most importantly, though, applying an IEA perspective to another issue with a similar problem structure has unlocked very counter-intuitive perspectives, raising important, thought-provoking questions. Transnational adaptation encompasses many other issues with similar problem structures, ranging from adaptation and biodiversity to adaptation in transboundary rivers, or adaptation of transport infrastructure. There is thus more to explore.

# 7 | Conclusions

International cooperation to avoid dangerous anthropogenic climate change has proven to be very hard to achieve. The difficulties to reach a binding international agreement with sufficient reduction targets are evident and extensively discussed in the economic literature. Nevertheless, new ideas towards cooperation are evolving. A selection of these new ideas regarding coalition structures, political economy and trade is analyzed in this thesis. The following section discusses the results of all chapters and their implications before the thesis concludes with a discussion of limitations of the presented research and an outlook on promising ways of further research.

## 7.1 Results and Implications

Chapter 2 provides an overview of emerging transnational patterns of cooperation with heterogeneous actors, taking stock of selected empirical examples of such patterns and of relevant publications from the global governance literature. A comparison with the economic IEA literature shows that although game theory allows to scrutinize important strategic effects of these patterns, they can only partially be explained by existing models so far. The proposed exemplary models for climate clubs and city alliances show that economic analysis can contribute to understanding these new forms of cooperation. The models indicate that climate clubs and city alliances may indeed improve over the situation with a single IEA consisting of nation states. As these proposed models are simple examples that mainly have expository character, the results have to be taken with caution and cannot provide sophisticated policy advice. The main conclusion from these modeling exercises is that it is possible and worthwhile to consider recent and new actors and coalitions in the game theoretical reasoning on IEAs. The proposed model structures may serve as a starting point for further modeling work. However, it is important to note, that the question of legitimacy of environmental agreements is increasingly difficult to answer if actors other than national governments have increasing importance in the negotiations.

Building on the proposed model structure from the previous chapter, the idea of climate clubs is explored more generally in Chapter 3 by analyzing multiple parallel IEAs. The results show that the possible effects of allowing for multiple coalitions depend on qualitative properties of the functions of benefits and damages from emissions. For decreasing marginal benefits and constant marginal damages, multiple coalitions increase the number of cooperating countries and reduces global emissions in comparison to a single IEA. In contrast, for increasing marginal damages and constant marginal benefits from emissions, the global amount of emissions is independent of the number of admitted coalitions. If both damages and benefits from emissions are non-linear, multiple coalitions can reduce global emissions below the level that can be achieved by a single coalition. Although admitting multiple coalitions does not always improve cooperation, they are not detrimental. This implies that the idea of climate clubs deserves more analytical attention and might be a promising avenue for international climate policies.

The decisions of national governments that do not only maximize welfare but are also influenced by lobby groups are in the focus of Chapter 4. The influence of lobby groups from the industry and environmentalists is shown to have effects on both the emission reductions of countries and the incentives to participate in an IEA. The influence of industry and environmental influence groups is quite intuitive as industrial contributions reduce emissions abatement and contributions from environmental lobbies lead to more ambitious reduction targets. Interestingly, green lobby groups in countries that are members of the IEA have effects on the decisions of all other member countries, whereas industry lobbies only influence their host countries decisions. This is due to the fact that damages from emissions occur on a global scale and environmental lobby groups seek to reduce these damages whereas the costs of emissions reduction, which industry lobby groups seek to avoid, occur only in the host country. The effects on coalition stability are more ambiguous and depend on the distribution of lobby activities across countries. Both, industry and environmental lobbies, can have a stabilizing effect on an IEA. These results qualify previous findings by Marchiori et al. (2017) that find a stabilizing effect for symmetric countries which is consistent with the findings of this thesis. However, the results additionally show that if countries are sufficiently asymmetric in their benefits from abatement industry contributions have a destabilizing effect. It can thus be concluded that lobby contributions have an important effect on both emissions reductions and coalition stability, with the latter being often not straightforward, depending on the composition of asymmetric countries in an IEA. This is important to note because countries in the climate negotiations are far from being symmetric in reality. The results imply that lobbyism should not be neglected in considerations about climate cooperation, neither in policy making nor in the theoretical analysis.

Chapter 5 provides an assessment of import tariffs as a means to stabilize climate coalitions. This policy measure has gained increasing attention with the papers by Lessmann et al. (2009); Nordhaus (2015). These studies have found that import tariffs can effectively foster international cooperation but rely on the assumption, that outsiders of an IEA are not able to retaliate if they are targeted by trade sanctions. In contrast to that, Chapter 5 explicitly considers the case of retaliation by outsiders by analyzing three policy regimes for the formation of an IEA: a regime without trade sanctions, a regime with trade sanctions in the form of uniform import tariffs used by coalition members against outsiders and a regime in which outsiders retaliate against these trade sanctions by using uniform import tariffs themselves. This is firstly done in an analytical model that confirms the established finding that trade sanctions without the possibility to retaliate might stabilize coalitions. However, if outsiders can retaliate, this results in a threshold effect: Above a certain coalition size, the stabilizing effect of trade sanctions enables larger coalitions whereas in coalitions below that coalition size the effect of retaliatory trade measures predominates and destabilizes the coalition. In a multi-region, multi-sector CGE model the analytical results are quantified. The quantitative results show that the threshold coalition size in the scenarios with trade sanctions and retaliation is well above 50% of world GDP across all assumptions about the global social cost of carbon. Trade sanctions as an effective stick to stabilize climate coalitions are therefore less attractive if the possibility of retaliation is taken into account. Only if substantial coalitions of countries that cover more than half of the global GDP have already formed they may help to establish the grand coalition. This is an important finding for international policy-making that currently has to deal with an increasing risk of trade wars with involvement of the US as an outsider of the climate coalition. If a climate coalition of insufficient size tries to force outsider countries to join and these react with retaliatory measures, this can destabilize existing coalitions or even destroy cooperation and lead to the non-cooperative outcome.

Finally, Chapter 6 revisits prominent recent findings from the IEA-Literature and explores potential insights that they can provide for climate adaptation in the presence of cross-boundary spillovers. The chapter finds that if adaptation measures contribute to the supply of a public good, these measures tend to be underprovided. The case of eutrophication in the Baltic Sea as a prominent example serves to discuss the role of multiple coalitions, side-payments, issue-linkage and trade sanctions for transnational adaptation. Whereas the potential of multiple coalitions, side payments and issue-linkage appears to be promising also for transnational adaptation, trade sanctions seem to be the least applicable approach. However, although the similarities between mitigation and transnational adaptation are present with regard to the general problem structure, concrete policy advice should preferably be derived from research that analyzes the concrete problems in greater detail. The more general work in Chapter 6 rather implies that insights from this thesis, like other results from the IEA-literature can help to find solutions to problems beyond the realm of climate mitigation as it is shown for the example of transnational adaptation.

## 7.2 Limitations and Outlook

With regard to the analytical game theoretical work conducted in this thesis some general limitations should be noted. Like all mathematical models, the game theoretical models in this thesis represent reality by simplification. This allows to focus the analysis on important strategic interactions but excludes many other aspects of the problems at hand. In reality these elements that are neglected in the models may play an important role and should thus be included in considerations about context specific policy measures. For such considerations, the analysis and results of this thesis can well be complemented by research from related fields such as political sciences, climate sciences and law, as it is partially discussed in Chapters 2 and 6. Other more specific limitations apply to different chapters of this thesis and could in some cases motivate further research.

While the results of Chapter 3 are quite general in the cases of either constant marginal damages or constant marginal benefits from emissions, the fact that the results for the case of both non-linear benefits and damages rely on numerical examples implies that the results in this case should be interpreted with caution, as it is not clear if the positive effect of climate clubs always holds in such cases. Further economic research in the area of climate clubs could provide insights about combining the idea of multiple coalitions with issue-linkage, as it is proposed by e.g. Weischer et al. (2012) and Widerberg and Stenson (2013). Other interesting questions for future research on the topic include the role of intra- and intercoalitional transfer schemes (c.f. Barrett, 2001; Fuentes-Albero and Rubio, 2010) and different sequences of the emissions game with some coalitions acting as Stackelberg leaders and moving before others. As the theoretical analysis in Chapter 4 does not include empirical data, calibrated quantitative simulations of theses strategic effects are a possible field for further research. The required challenging quantification of lobby influences on governmental decisions on the formation of IEAs could possibly draw on empirical work by Fredriksson et al. (2007). In contrast to Chapter 4, Chapter 5 includes a quantification of the analytical results. The important threshold for a minimum coalition size in which trade sanctions can help to stabilize climate agreements is found to be above 50% of world GDP. Such a threshold motivates further research that could explore the applicability of minimum participation rules for the use of trade sanctions in climate agreements. This would connect the work in Chapter 5 with previous literature on minimum participation rules in IEAs (e.g. Weikard et al., 2015; Carraro et al., 2009; Harstad, 2006; Rutz, 2001). The quite general work in Chapter 6 can serve as a starting point for further research that could develop more detailed models for problems like transnational adaptation that are related to the IEA literature by building on advances in coalition theory that have been made with a focus on mitigation. Similarities and differences in the details of the structures of the problems might be important for the design of policy measures so that a translation of findings from the IEA literature to other fields of international cooperation requires careful analytical consideration. The first findings in this thesis indicate that it may be worth the effort.

In a changing global climate regime the search for new avenues of cooperation is crucial for effective climate policies. However, the established economic literature on IEAs has only sparsely payed attention to such approaches. This thesis provides an attempt to enrich game theoretic analysis of environmental cooperation and incorporate findings from the global governance literature and consider the political economy and the trade regime. The results imply that it is worthwhile to broaden the scope of analysis in these directions as this may indeed help to find viable options to increase cooperation. Climate policies increasingly consider new strategies beyond nation-state actors and economics should be prepared to provide strategical advice.

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